SNS-104040400-DE0001-R00

Spallation Neutron Source

Coupled Cavity Linac Vacuum System

Final Design Report

(SNS-104040400-DE0001-R00)

by:

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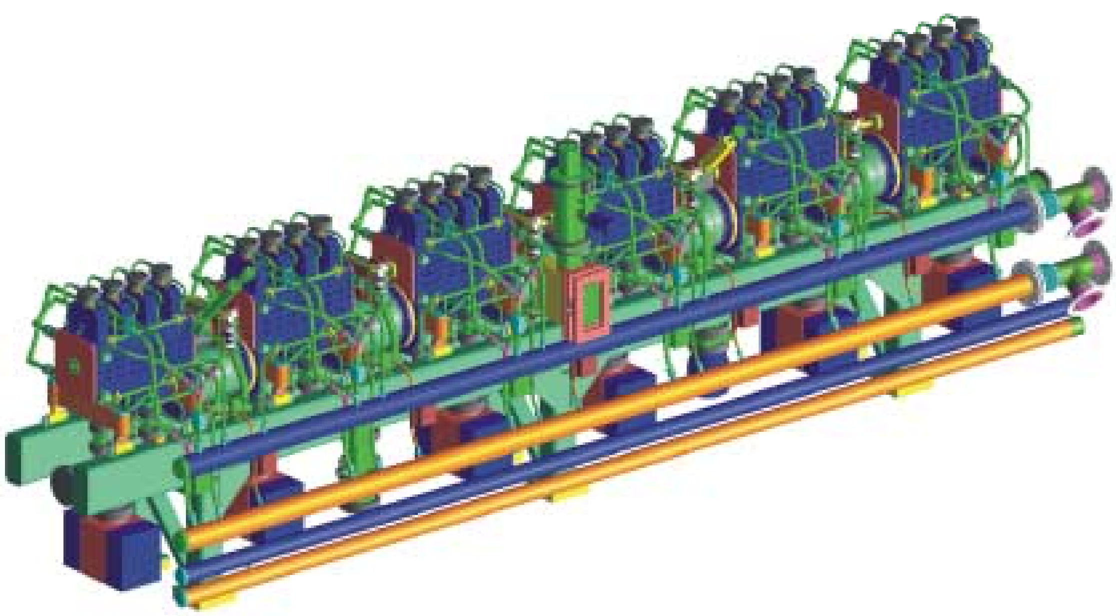

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1.0 Introduction

The Spallation Neutron Source (SNS) is an accelerator-based neutron research facility being designed for scientific and industrial research and development. Specifically, SNS will generate and use neutrons as a diagnostic tool, much like X-rays, for medical purposes as well as physical, chemical, biological, and material sciences. The SNS will produce neutrons by bombarding a heavy metal target with a high-energy beam of protons, generated and accelerated with a linear particle accelerator, or linac. To effectively accelerate the protons, the linac requires an evacuated environment. This vacuum serves two purposes. First, the gas pressure in the accelerating structure must be minimized ($<10^{-6}$ Torr) to provide an acceptable environment for the Radio Frequency (RF) electrical energy to propagate within the copper structure. If the gas pressure is too great, high electrical fields established by the RF will tend to arch or locally discharge electrons between copper surfaces, which could damage the structure. Second, a low gas density is required along the beam line to minimize collisions of the accelerated protons with gas molecules. These undesirable collisions create stripping or scattering of the protons, which results in activation of the surrounding structures and reduce the beam power delivered to the target.

One of the primary accelerating structures is the Coupled Cavity Linac (CCL), which accelerates the SNS proton beam from 87 MeV to 185 MeV. The basic design features of the CCL can be found in [1.1] and are summarized briefly in Section 1.4 of this report. A preliminary design for the CCL vacuum system was completed in June of 2000, and documented in [1.2]. This report summarizes the final design of that CCL vacuum system.

1.1 Project Scope, Deliverables, and Design Criteria

The complete project scope associated with the CCL Vacuum System includes the design, analyses, fabrication, assembly, installation, testing, and certification of the vacuum system components. The efforts associated with this project scope include performing final design engineering calculations and developing corresponding engineering drawings, preparation of procurement packages, liaison with vendors and participation in assembly, installation, and testing at Oak Ridge National Laboratory (ORNL).

This report covers the final design efforts, based on a preliminary design outlined in [1.2]. To develop a functional, reliable, and affordable vacuum system, the following final design deliverables were identified [1.3]:

1. Revision of preliminary design aspects as directed by LANL SNS-PO following the CCL Vacuum System PDR [1.4].
2. Completion of all engineering calculations.
3. Completion of P&IDs as well as assembly and detail drawings for the pumping stations, vacuum manifolds, support structures, etc.
4. Complete design of instrumentation, controllers, and software for the local control system and global control system integration plans.
5. Specifications and procedures for vacuum system material preparation, cleaning, handling, and shipping.
6. Completion of detailed mechanical drawings and procurement plans with bill of materials for procurement of off-the-shelf items and fabrication plans for specialized components.
7. Completion of assembly, installation, testing, and certification/quality assurance plans.

Table 1.1 lists the general design criteria that were applied to the SNS CCL Vacuum System design. Each criterion has a brief description and a weighting factor associated with it. The weighting factor is intended to give a measure of the criterion's importance in the overall CCL vacuum system design, and consequently, assist the engineering design team in selecting between various design alternatives. An example of the use of the design criteria and weighting factors in assessing two different design alternatives can be found in [1.3].

Table 1.1. SNS CCL vacuum system design criteria.

Design Criteria	Weighting Factor♣	Description
Functionality	5	• Base pressure must be met (pumps must overcome outgassing and leaks) • Vacuum hardware must not interfere with support structure • Vacuum system must be resilient to react to beam line expansions/adjustments
Safety	5	• Proper controls and safety features, following appropriate DOE guidelines, should be employed to protect personnel and the beam line (equipment and operation)
Procurement, Fabrication, Assembly	3	• Design with standard, off-the-shelf parts • Avoid using exotic materials • Assembly and maintenance issues should be incorporated in the design to ensure compatibility with other subsystems (i.e, support structure, water system, etc.)
Durability/ Reliability	4	• A reliability assessment should be performed to ensure the vacuum system performs to a satisfactory level (minimize down time). • Vacuum pumps should be selected for **30** year lifetime and have a 5 year maintenance period. • The pumping speed must be designed with a safety margin of 2 in the beam tube pressure (i.e, designed vacuum pressure will be half the value of the required operational pressure) to account for pump failure, leaks, or unforseen gas loads, and still allow for accelerator operation.
Cost	4	• Optimize functionality to minimize procurement, fabrication and assembly costs to fit within the allocated budget (based upon the conceptual design)
Maintainability	3	• Vacuum pumps and hardware should be accessible for maintenance/replacement with minimal impact on beam down-time
Consistency	2	• Every effort should be made to use the same type of vacuum components throughout the Linac. In addition, these components should be consistent with those used elsewhere in the SNS facility (i.e., RFQ, storage ring, target, etc)

♣ 5 = very important, 1 = least important

1.2 Coupled Cavity Linac Vacuum Environment

The SNS linear particle accelerator, or linac, is comprised of three main structures including the Drift Tube Linac (DTL), the Coupled Cavity Linac (CCL), and the Super Conducting Linac (SCL), as displayed in Figure 1.1. The first proton accelerating structure following the ion injector and RFQ, is the DTL. The 402.5 MHz Alverez DTL [1.5], is used to accelerate the H- beam from 2.5 MeV to 86.8 MeV. Following the DTL is the CCL, which further accelerates the H- beam from 86.8 MeV to 185 MeV. The SNS CCL is comprised of four modules. Each module is comprised of twelve accelerator segments, with each segment housing eight accelerator cavities. Figure 1.2 displays a complete CCL module and the associated terminology.

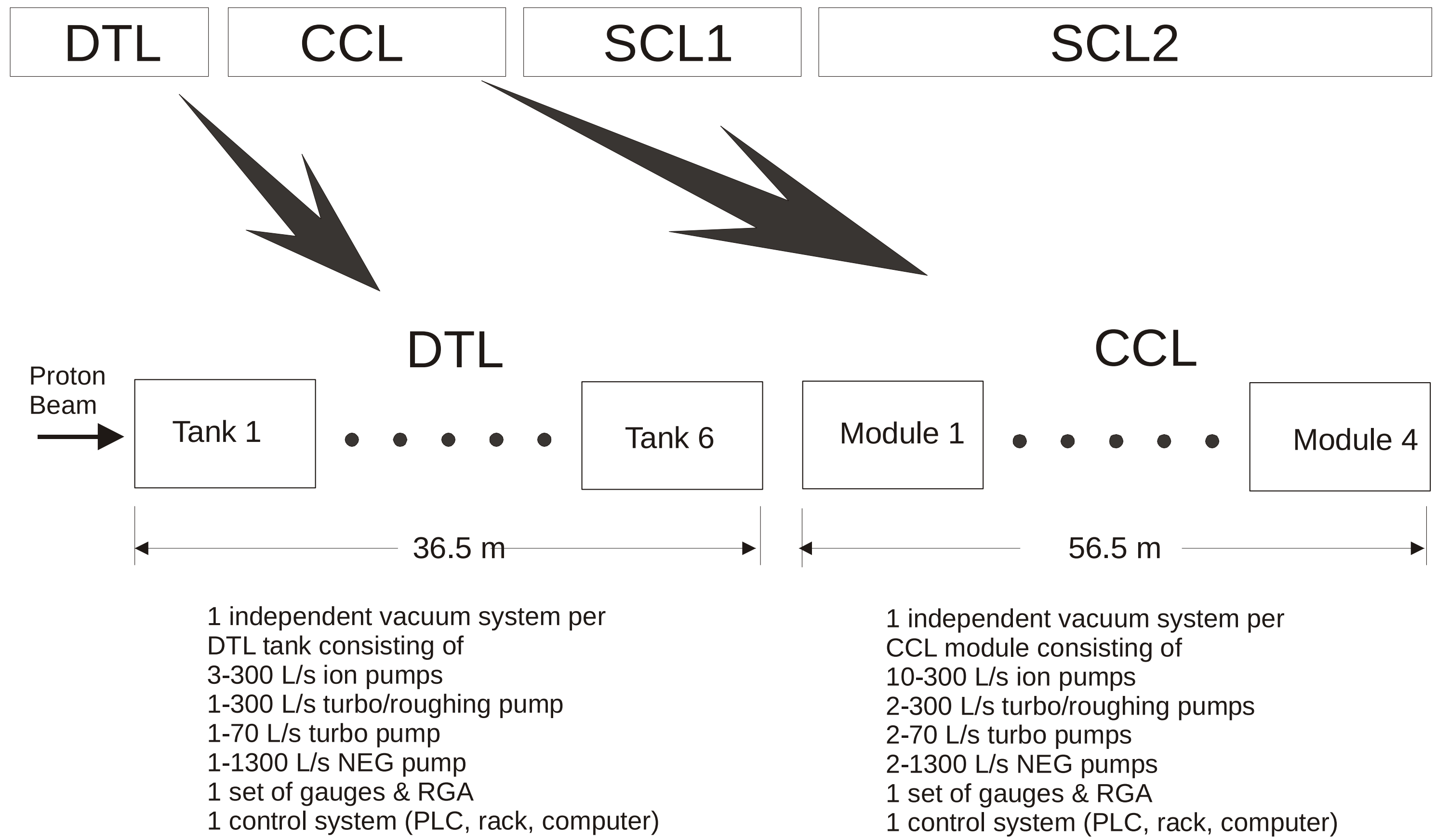


Figure 1.1. General layout of the SNS Linac and basic summaries of the DTL and CCL vacuum systems.

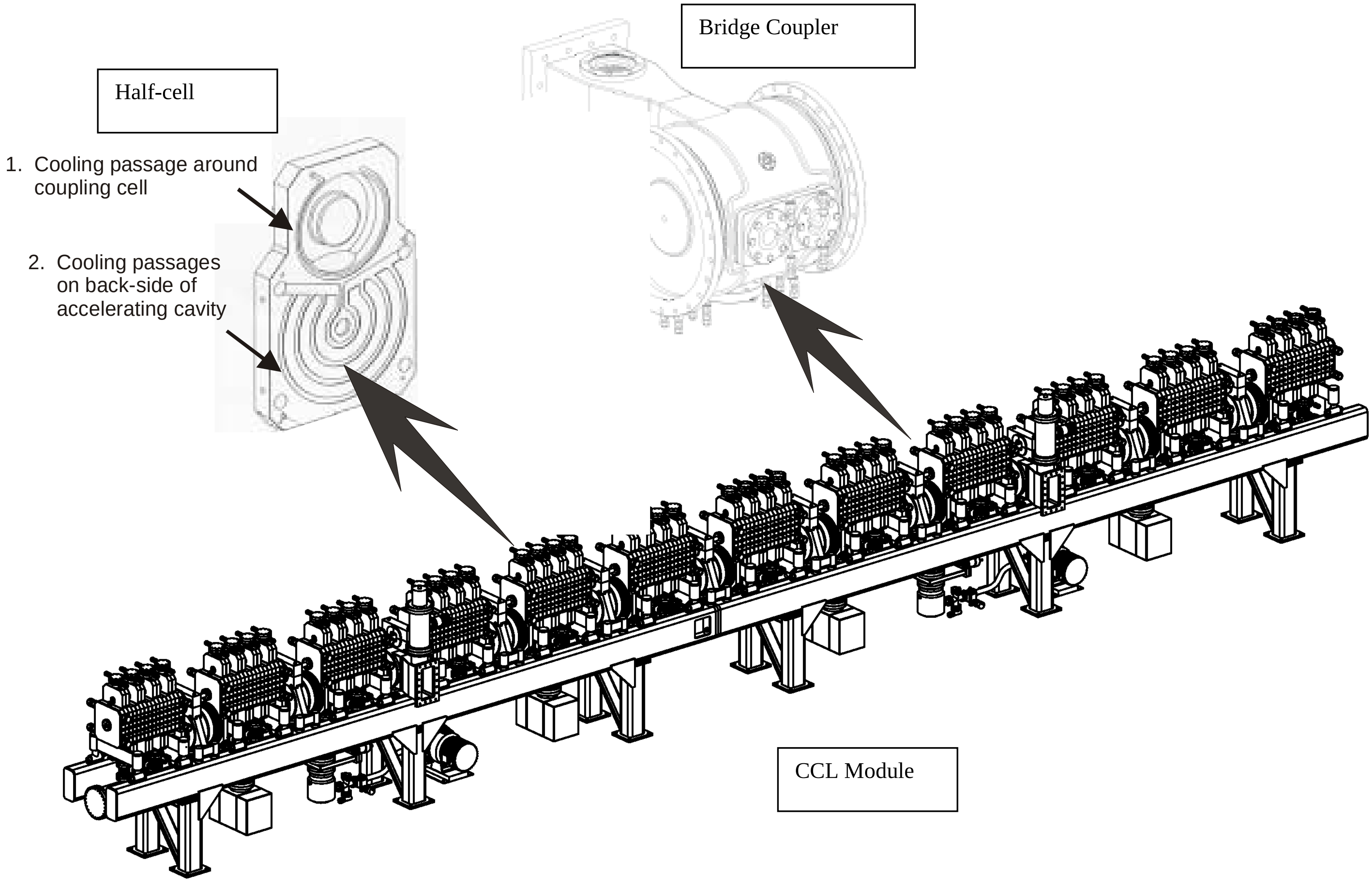


Figure 1.2. Complete assembly drawing of a CCL module with details of a half-cell and bridge coupler.

The module identification number, module length, number of segments and cavities are summarized in Table 1.2.

Table 1.2. Basic partitioning characteristics of the CCL modules in the SNS Linac.

Module #	Length of Module (m)	# of Segments per Module	# of Cavities per Segment	# of Cavities per Module
1	12.2	12	8	96
2	13.3	12	8	96
3	14.5	12	8	96
4	15.5	12	8	96

A more detailed description of these components and their functionality can be found in [1.1] and [1.5].

For a single CCL module, the vacuum environment can be essentially divided into three main regions, as displayed in Figure 1.3. The first and largest vacuum region is the CCL cavity and side coupling cell volumes. These volumes make up the majority of the vacuum environment and contribute the greatest amount of gas from surface outgassing, seal leaks, and loads from the intersegment regions. The second vacuum region concern is the volume between the RF window and iris, located on the tank wall near the mid-way length of the tank body. The RF window has the potential to be a large gas load, as it is porous and the trapped gas molecules get released when excited by applied RF energy. The iris, which is a narrow slit in the tank wall, has a large conductance and is not efficient for pumping through. Consequently, the waveguide transition housing between the RF window and iris, forms a vacuum region that is nearly independent of the tank volume. The third vacuum region corresponds to the region between the CCL modules. The gas loads in this region arise from outgassing of beam diagnostic equipment within the inter-segment beam box spaces and seals.

Section 3 of this report contains detailed numerical and analytical vacuum analyses to estimate the required pumping speeds and obtainable base pressures to overcome the gas loads of each of these three vacuum regions.

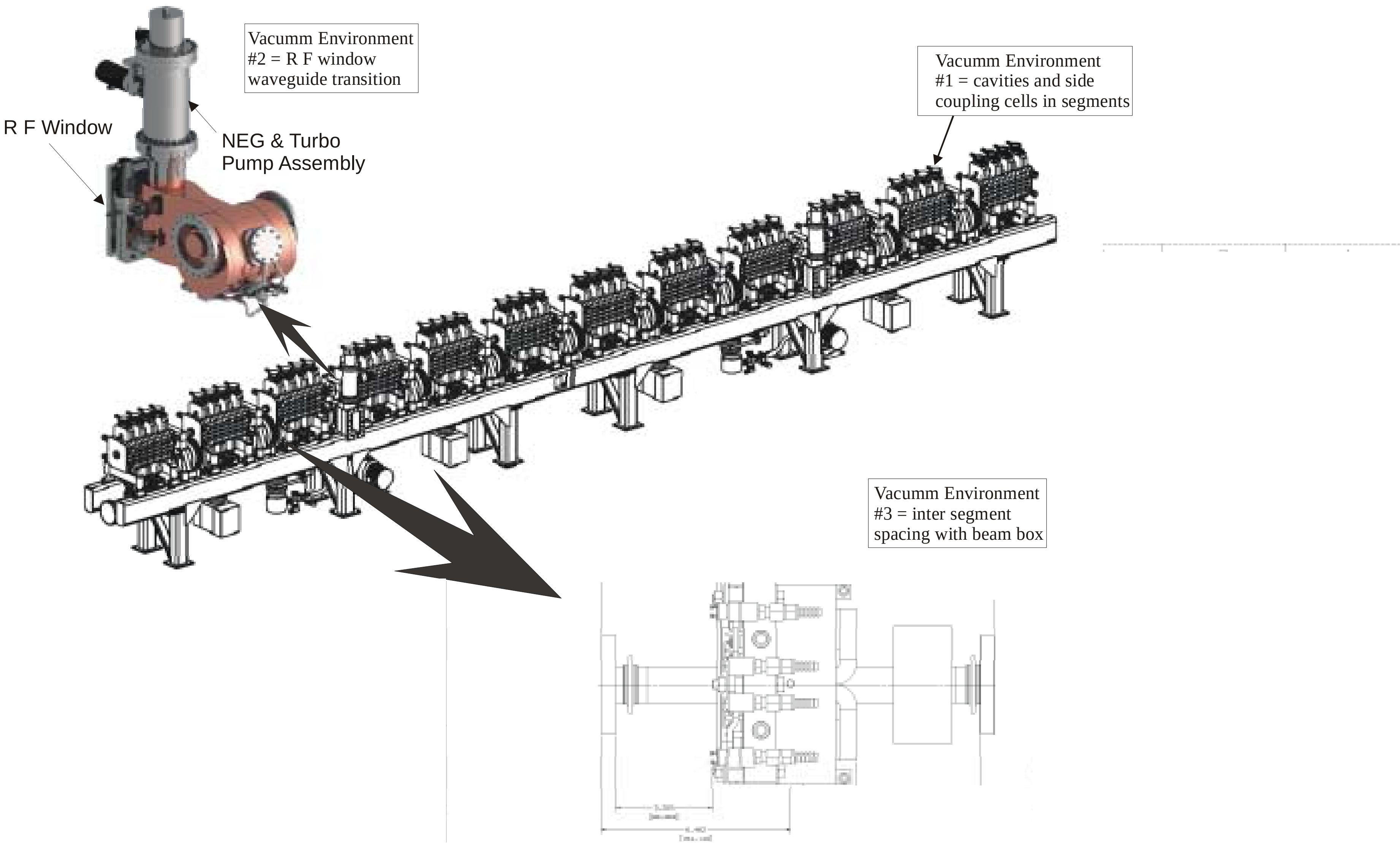


Figure 1.3. The three primary vacuum environments in the CCL vacuum system.

1.3 CCL Vacuum System Design Summary

The preliminary and final designs of the CCL vacuum system have been completed. The basic vacuum system features are as follows:

- Each CCL module vacuum system will have the capability of being isolated from its neighboring modules (with discontinuous vacuum manifolds and beam-line isolation valves). While the vacuum pumps may be operated in a manual mode (via their own controller), for such things as leak checking and vacuum conditioning, one local controller will supervise and operate the vacuum systems on a modular basis.
- All main vacuum pumps will be attached to the bottom of the CCL RF structures by a sectioned vacuum manifold that runs the length of a module.
- A turbo/roughing pump combination will condition each CCL module and serve as transitional pumping to a suitable base pressure (10^{-6} Torr) to allow for ion pump operation. Ion pumps will provide for the steady-state vacuum pumping.
- A nonevaporatable getter pump and a small turbo pump will be needed near the RF window (iris) to supply the additional pumping requirements needed to compensate for potentially high outgassing rates from the window during conditioning.
- Electropneumatic vacuum isolation valves (with positioning output signal for safety interlock) will be required between each CCL module (and at the ends of modules 1 and 4) for vacuum isolation. This will ease vacuum leak checking, vacuum conditioning and system operation certification, and all-around maintenance. Electropneumatic actuated vacuum isolation valves (with positioning output signal for safety interlock) will be required between the turbo pump and NEG pump on each RF window vacuum pump assembly and also at each turbo/roughing station location.
- A low vacuum and a high vacuum gauge will be needed on each module for system operation (i.e. when to turn on ion pumps), vacuum monitoring (current pressure), and safety interlocks (vacuum or other subsystem failure). An RGA attached to each CCL module will provide critical vacuum system data during the early conditioning periods and provide a means of trouble shooting during the lifetime of the accelerator. The RGA controller will be located outside of the linac tunnel to prevent radiation damage to the controller's electronics.
- Nitrogen purge lines with pressure regulators, gas-flow throttling devices, and relief valves will allow the CCL modules to be safely back-filled with dry nitrogen gas during maintenance periods.
- A local control system will be provided for every CCL module and will monitor all vacuum pumps, valves, and instrumentation. This system will provide for vacuum conditioning of the CCL modules prior to beam operation. The local control system will interface with the SNS global control system and provide for vacuum system operation and monitoring, data storage, and safety interlocks.

1.4 Vacuum Requirements

The primary requirement for the DTL and CCL vacuum systems is to provide sufficient pumping to overcome the surface outgassing of vacuum facing components and maintain a beam tube pressure that is below the values required for a 2-mA H^- beam operation. The vacuum requirements for the DTL and CCL, given in Table 1.3, were determined from calculations involving the stripping of the proton beam by gas molecules in the vacuum environment [1.6]. The underlying criterion for the vacuum levels is the acceptable activation of linac hardware. For the SNS linac, a maximum radiation dose rate was defined to be of 10 mrem/hr at 1 ft from the linac, 4 hours after shutdown following a 100 consecutive day run. Using this activation criterion and basic proton scattering/activation theories, an H^- scattering model was developed to determine the acceptable vacuum pressure levels in the SNS linac. The model shows that the amount of H^- scattering and the associated activation of linac hardware, is directly proportional to the linac beam energy and gas specie partial pressure within the vacuum environment. As the beam energy increases, the amount of beam scattering increases for constant vacuum pressure. Consequently, the allowable vacuum pressure along the DTL and CCL must decrease as the proton beam energy increases from 2.5 MeV to 185 MeV. In addition, since the H^- scattering is highly dependent on the cross-section of the gas molecules present in the beam tube, the allowable vacuum pressure is gas species dependent. The maximum allowable beam tube pressure, $P_{allowable}$, is a weighted sum of the individual gas specie partial pressures, P_{sub}:

$$P_{allowable} = W_{He}\, P_{He} + W_{H2}\, P_{H2} + W_{H2O}\, P_{H2O} + W_{N2}\, P_{N2} + W_{CO}\, P_{CO} + W_{O2}\, P_{O2} + W_{CO2} P_{CO2}$$

where the weighting factors for the primary gas constituents of interest are as follows:

W_{He} = 0.125 (helium)
W_{H2} = 0.15 (hydrogen)
W_{H2O} = 0.66 (water)
W_{N2} = 1.0 (nitrogen)
W_{CO} = 1.0 (carbon monoxide)
W_{O2} = 1.0 (oxygen)
W_{CO2} = 1.5 (carbon dioxide)

Note that these weighting factors reflect the ability of the corresponding gas molecules in scattering the high energy protons. The maximum allowable pressures in the DTL and CCL, as a function of beam energy, are given in Table 1.3. Note that these pressures correspond to an average pressure measured over a beam tube length of 5 meters.

Table 1.3. Vacuum pressure limits along the beamline in the DTL and CCL.

Linac Section	**DTL Tank or CCL Module**	**Exit Beam Energy**	**Max Allowable Pressure**
	No.	**MeV**	**Torr**
DTL	1	7.5 (starts at 2.5)	1.84×10^{-7}
DTL	2	22.8	1.84×10^{-7}
DTL	3	39.8	1.84×10^{-7}
DTL	4	56.6	1.84×10^{-7}
DTL	5	72.5	1.84×10^{-7}
DTL	6	86.8	1.84×10^{-7}
CCL	1	107.2	1.84×10^{-7}
CCL	2	131.1	1.53×10^{-7}
CCL	3	157.2	1.21×10^{-7}
CCL	4	185.6	0.89×10^{-7}

Additional vacuum system design requirements, such as space envelopes, acceptable pumps and materials, interfaces, etc. can be found in [1.3] and [1.8].

1.5 Mechanical and Electrical Interfaces

The key mechanical interfaces between the CCL Vacuum System hardware and the CCL RF structure are summarized in Table 1.4. Further mechanical and vacuum analyses that relate to these interfaces can be found in Sections 3 and 4 of this document.

Table 1.4. Mechanical Interfaces between the CCL Vacuum System and CCL RF structure.

Interface Description	Mechanical Connection	Vacuum Impact
Vacuum Manifold Bellow Connection to Side Coupling Cells	Bolted Conflat flange	RF shielding is not required for the bellow ports
Vacuum Manifold	Bolted, adjustable mount	Manifold mounting influences bellow design (lateral deflection of bellows needed for misalignment and machining limitations)
RF window pump ports	Bolted Conflat flange	RF shielding is required for pump port
Vacuum isolation valves	Bolted, metal or polymer o-ring seals	• Isolation valves will be pneumatic with position indicators. • Beamline valves provided between modules where clearance is available. • Turbo cart valves provided between pump port and pump cart.
CCL RF structural components	Metal "C" seals will be used at the vacuum connections for the intersegment beam tubes and bridge couplers to the segments.	• All seals will be of the knife-edge, spring seal, or polymer o-ring type. All polymers subject to radiation hardening requirements as detailed in Section 4. • All CCL structural components in vacuum environment will be cleaned to specifications given in the Appendix of this report. All engineering drawings will specify these cleaning specs and require review and approval of a vacuum engineer.
CCL beam diagnostic equipment	Varios mechanical and electrical feed-throughs.	• All seals will be of the knife-edge, spring seal, or polymer o-ring type. All polymers subject to radiation hardening requirements as detailed in Section 4. • All CCL structural components in vacuum environment will be cleaned to specifications given in the Appendix of this report. All engineering drawings will specify these cleaning specs and require review and approval of a vacuum engineer. • Total outgassing rate for beam diagnostic equipment in a single location will be kept below levels specified in Section 3 of this report.

All equipment (pumps, instrumentation, valves, etc) shall operate from the linac tunnel and klystron gallery utilities. The SNS conventional facility requirements for the Linac are specified in [1.7]. Table 1.5 lists the electrical requirements for typical pieces of vacuum equipment needed in the CCL vacuum system, while Table 1.6 summarizes the required utilities (based on the final design) for the CCL vacuum systems. In addition, the electrical requirements listed in Table 1.6 do not include any surpluses required by electrical codes. In case of an electrical power failure, uninterruptible electrical power service (UPS) will be required for the vacuum diagnostics and PLC for the CCL vacuum systems, as shown in Table 1.7. The UPS will permit the operators to determine vacuum conditions prior to an overall system restart once electrical service is restored.

The communication interfaces between the CCL Vacuum Control System and the SNS Global Control System are described in detail in Section 5 of this report.

All other facility-type interfaces are covered in Section 6 of this report.

Table 1.5. Summary of electrical requirements for various pieces of vacuum equipment on the CCL vacuum systems.

Equipment	Voltage (volts)	Phase	Start-up current (Amps)	Steady-state current (Amps)
Scroll pump	120	1	12	7
Turbo pump (300 L/s)	120	1	4	1
Ion pump (300 L/s)	120	1	2	0.5
NEG pump (1300 L/s) controller	120	1	9	9
Turbo pump (70 L/s)	120	1	1	0.25
Backing pump for small turbo	129	1	4	2
RGA	120	1	4	4
PLC & IOC	120	1	4	4
Gauge Controller	120	1	0.5	0.5

Table 1.6. Summary of SNS building utilities required for the CCL vacuum systems.

Linac Structure	Air line pressure in tunnel for vacuum valve actuation	N_2 gas purge available in tunnel	Electrical in linac tunnel (Qty/KVA/V/Phase)	Electrical in klystron gallery (Qty/KVA/V/Phase)
CCL	125 psia	Yes	8/2.0/120/1 (turbo cart)	8/3.0/120/1 (elec. rack)

Table 1.7. Summary of UPS requirements for the CCL vacuum systems.

Equipment	Voltage (volts)	Phase	Start-up current (Amps)	Steady-state current (Amps)
RGA	120	1	4	4
PLC & IOC	120	1	4	4
Gauge Controller	120	1	0.5	0.5

1.6 Comments and Action Items from Preliminary Design Review

The DTL/CCL vacuum system preliminary design review (PDR) committee's comments and the corresponding design team responses and/or actions are given in Table 1.8. Each item of concern that was raised by the PDR committee has been addressed and documented in this final design report.

Table 1.8. Preliminary design review committee comments and corresponding responses or actions taken during final design of the DTL/CCL vacuum systems.

Comment #	**Review Committee Comment**	**Design Team Response or Action**
1	The "design goals" require further clarification in regard to their application of "design margins".	A vacuum pressure design margin of 2 has been defined in the vacuum design criteria (and agreed upon by ORNL-ASD). Consequently, the vacuum system will be designed to achieve, under normal operation, an operational base pressure that is half of the required operating pressure value. This design margin will allow the vacuum system to still achieve operational pressures in the event of higher gas loads (from dirt, virtual leaks, unaccounted gas loads) and/or pump failure.
2	The interface with the RF, beam Interrupt, and mechanical structures require clarification.	A control system interface diagram was developed that identifies all signal/communication interfaces with the DTL/CCL vacuum systems and other control systems (global, low-level RF, RF power, etc.). Assembly drawings of the DTL and CCL were generated to look at mechanical interfaces of the vacuum system with the RF and support structures, as well as other subsystem hardware.
3	The RF window vacuum system needs further optimization. Additional window outgassing data needs definition.	Further optimization and design of the RF window vacuum system occurred. Additional outgassing data will become available from the CCL hot model testing in the upcoming months.
4	Evaluation of turbo-pump carts compared with permanently installed turbo-pump stations must be performed.	Mechanical positioning and clearance of a portable turbo cart with the DTL and CCL RF structures was studied and a turbo cart specification sheet was generated. In addition, the oughing pump-down time of a DTL tank and a CCL module as a function of turbo pump speed was calculated to determine number/size of carts.
5	Include water vapor pumping in analysis	The vacuum pressure design criterion is a weighted function of partial pressures of multiple species. Multiple gas species were included in the DTL tank and CCL module vacuum models through the use of superposition. The % distribution of gas species in the gas load was determined from LEDA hot model RGA data.
6	"design margin is to provide excess capacity utilized when an off normal event occurs…"	In the PDR, the design margin was also used to cover unknown scenarios not covered in the model such as dirty surfaces, virtual leaks, outgassing of diagnostics, etc. The design margin of 2 has been defined to cover pump failure and unforeseen gas loads. See response to 1st comment.
7	The determination of the conditioning and recovery times for the vacuum systems must be conducted to insure that the availability budgets for the respective linac systems and the conditioning schedules are not exceeded.	The RAMI plan that was initially developed by ORNL has been replaced by the incorporation of "good engineering practices" to ensure good availability. Consequently, the availability studies that were planned have been canceled. The vacuum conditioning schedule should not impact the overall conditioning of the Linac as long as proper cleaning and handling procedures for all vacuum hardware have been followed and hence the vacuum conditioning time is minimized.
8	The use of dual pump controllers across tanks or modules should be considered if they can be accessed and	Dual pump controllers was investigated but not found to integrate properly with the vacuum control system architecture and modularization scheme or produce any significant cost savings..

	replaced with spare units without shutting down the accelerator.	
9	The use of seal type, especially in the DTL Tank, should be investigated by the responsible design personnel to avoid future performance degradation by elastomer seals. Historical data from LANSCE indicates that a backing vacuum system was required at a later date to accommodate this occurrence while the DTL elastomer seals at AGS has had no difficulty over 30 years. The failure mode of the LANSCE seals needs to be further investigated and documented.	All vacuum seals and penetrations on the DTL and CCL RF structures were identified and reviewed by the vacuum system design team for vacuum compatibility and engineering design. Leak rates associated with all seals were included in vacuum models and found to be acceptable. Use of elastomer seals was based on acceptable leak rate levels, radiation compatibility, design functionality, cost, etc.
10	Personnel responsible for the vacuum must be directly involved in the design activities of all accelerator components that have a vacuum interface, from conceptual through final design phases, of all accelerator system. There is a sense of disconnection at this time.	LANL/SNS Division is implementing appropriate procedures. Plans have been developed to review the relevant hardware designs of the DTL and CCL RF structures (valves, seals, cleaning procedures, materials), beam diagnostic equipment, drift tube permanent magnets, etc.
11	Personnel responsible for the vacuum must have sign off responsibility for all final release drawings for components that connect to the vacuum system.	LANL/SNS Division has implemented appropriate procedures. Vacuum engineer approval signature box has been added to the SNS drawing template title block.
12	The number, type, and configuration of in-vacuum diagnostics need to be defined and the outgassing effects evaluated during the design stage of that equipment.	A tabulation of the types, quantities, and locations, as well as descriptions of the designs/materials of the beam diagnostics hardware are being generated. Engineering vacuum calculations have been performed to define allowable loads requirements for all diagnostics.
13	DTL component gas loads and dimensions to be revised to reflect latest design	The numerical models were updated with the current DTL and CCL design parameters such as component geometries, outgassing rates, and seal types/quantities/gas loads.
14	latest geometry’s to be incorporated	The numerical models were updated with the current DTL and CCL design parameters such as component geometries, outgassing rates, and seal types/quantities/gas loads.
15	outgassing rates > 100 hrs should be included for accident scenario	Outgassing rates have been defined to account for species concentrations and dependence on vacuum and RF conditioning times. Some limited outgassing data does exist (from LEDA hot model RGA data) and has been referenced in the DTL/CCL vacuum FDR reports.
16	Utilize superposition to study other gas species such as water	Superposition of multiple gas species and weighted partial pressure design criterion (Shafer, 1999, “Beam Loss from H-minus Stripping in the Residual Gas,” TN:LANSCE-1:99-085) was employed in DTL & CCL vacuum models.
17	Analytical Enhancement: the seismic levels used for the structural evaluations need to reflect the official project definitions.	The official seismic design requirements for the SNS project were incorporated in the mechanical strength analyses.
18	Inclusion of turbo pump stations during off-normal operation should not be	This recommendation has been included in the vacuum system design.

	addressed as a necessary feature.	
19	Standardization: the standardization of components with other machine areas shall be addressed as a priority, this shall include equipment specifications and associated procurement activities.	We have worked with BNL, JLAB, LBNL, LLNL, and ORNL engineers and held vacuum standardization meetings to identify common components and strive to standardize the specifications and procurement of these items during the final design phase. ORNL-ASD is constructing a vacuum standards handbook (with input from all SNS participating labs) to identify common design practices, hardware selection, and manufacturing/cleaning procedures. Vacuum hardware specification sheets have been developed to identify needed/desired design features of the DTL/CCL vacuum equipment and will be submitted to ORNL for incorporation in the project procurement plan. It was decided that basic ordering agreements will be set up by ORNL for the partner labs to procure vacuum hardware from selected vendors.
20	Recommend diode ion pumps	The desired pumping speed and other pump characteristics were listed in an appropriate ion pump specification sheet. These DTL/CCL ion pump specifications will be reviewed by the ORNL-ASD to determine consistent ion pump selection with other SNS vacuum systems.
21	Standardization: procedures for operations such as cleaning need to be standardized to ensure comparable levels of cleanliness.	LLNL already has a set of comprehensive, robust specifications for cleaning vacuum system hardware. These specifications will be supplied to all DTL/CCL hardware designers to ensure proper cleaning of all materials entering the vacuum environment. We will make these specifications available to the other SNS vacuum system design teams during the final design phase.
22	The effect of arcing, multi-pactoring, and electro-magnetic interference in the DTL tanks must be evaluated. Do peak RF fields exceed dielectric strengths? What is the waveguide cut-off for the pump ports? Do higher order modes propagate to the pumps and gauges?	Many of the questions concerning the electric field parameters can not be appropriately responded to by the vacuum design team. These questions will be passed along to the RF engineers and cavity design physicists and dealt with during the DTL RF structure PDR. The issues concerning the RF shield design on the pump ports was addressed by the vacuum design team during final design. The pump RF shield design was also reviewed by the vacuum team. The absence of RF shields on gauges and the CCL vacuum manifold, has also been justified.
23	The 10^{-10} Torr L/s/cm^2 surface outgassing rate for the DTL tank walls due to RF conditioning should be verified	The DTL tank is lined with copper which should have a pre-RF conditioned outgassing rate similar to clean copper surfaces referenced in the literature and documented from the APT/LEDA CCDTL hot model test. During RF conditioning, the RF field interaction with the DTL tank walls will be much less than that experienced on the CCDTL hot model cavities, and hence the RF conditioned gas load documented for the LEDA hot model, may not be appropriate to use in the DTL vacuum model. It is reasonable to expect that the DTL gas load (on a per unit surface area basis) during RF conditioning will be lower than that seen on the CCL and LEDA hot model due to lower RF interaction with the DTL tank walls. Consequently, the gas loads on the DTL will not decrease as fast as they should for the CCL. All of this was considered in establishing species and conditioning time dependent gas loads which were incorporated in the vacuum models.
24	DTL RF seals design – “virtual leak”	The designs of all RF and vacuum seals in the DTL and CCL (currently designed by the RF structures engineers) were reviewed by vacuum engineers to ensure that the seal materials satisfy radiation exposure criteria and do not serve as virtual leaks.
25	Correlate gauge locations with beam pressure predictions	This data was obtained from the DTL and CCL vacuum models. This pressure correlation information has been provided in the vacuum system FDR report and the beam tube pressure predictions (from gauge measurements) will be displayed on control system operating screens.
26	The mechanical support for the vacuum pumps off the floor should be considered to alleviate any structural impact on the DTL tank.	Stress analyses of the DTL and CCL ion pumps determined that additional mechanical support (in addition to the attachment flange) was unnecessary.
27	The spool pieces between the DTL tanks and the pumps needs to be finalized.	The DTL and CCL vacuum instrumentation spool piece designs have been completed.

28	The possibility of encasing the ferrite magnets in copper shrouds, providing cooling and reducing outgassing should be considered.	Cooling isnot required for permanent magnets. We have defined maximum allowable outgassing rates of drift tube bores and compared this to the magnet outgassing load. The magnet gas loads were found to be acceptable.
29	Increase roughing time on tanks 2-6	Our model shows that the 30 min. roughing time is adequate to achieve a pressure to initiate the turbo. Why increase the roughing time? Please clarify this question.
30	Can the two manifolds on one CCL module be joined by a bellows and utilize a single roughing port?	A single manifold, sectioned in 2 pieces and joined by a bellows, has been designed for a single CCL module vacuum system. The manifold design was based on vacuum pumping requirements, manufacturing limitations/costs, and assembly/installation requirements.
31	The clearance and mounting of the CCL modules needs to be addressed with the assembly drawings of the module structure support.	The assembly drawings of the CCL vacuum manifold and mounting fixtures were incorporated in the top level CCL module assembly drawing to ensure that the vacuum components (manifold, bellows, pumps, etc.) would interface properly with the RF and support structures.
32	The bellows attachment configuration between the CCL RF structures and the manifolds needs to be finalized.	The bellows design has been finalized to ensure that it forms the proper interface between the CCL side coupling cells and vacuum manifolds. The flange attachments, clearances, and positioning of the bellows have been verified with the use of a top level CCL assembly drawing which combines the RF structure, the support structure, and the vacuum equipment. A uniform formed bellows design was selected for use on all CCL vacuum manifolds. The lateral and axial deflections of the bellows are more than sufficient (by a factor of 2) to handle the misalignments due to machining, assembling, and aligning errors. The forces induced on the CCL by mis-aligned bellows was found to be neglible.
33	The impact of the vacuum force on the CCL RF structures & alignment need to be evaluated.	This analysis has been performed.
34	The stepping down of the air pressure from 120 to 90 psi versus using separate manifolds for the different valve actuation pressures should be considered.	This recommendation was implemented.
35	A verification of the back-up and uninterruptable power requirements should be verified.	The back-up electrical requirements for the DLT/CCL vacuum systems have been completed and documented in the SNS DTL/CCL Vacuum System Description Document. The UPS requirements have also been submitted directly to the SNS conventional facilities team. Enough UPS will be supplied to keep the vacuum system PLCs and pressure gauge controllers active should a power failure occur.
36	Need to derive conditioning plan for DTL & CCL to determine simultaneous pump-down requirements.	A review of the assembly, installation, and commissioning schedules for the DTL and CCL was conducted. The current schedule indicates sufficient time to vacuum condition the DTL and CCL with the quantity of turbo pump carts available..
37	Attempt to minimize number of logic points in the event of a vacuum failure.	Number of logic points will be minimized during the PLC programming phase. Loop run times will be documented along with communication and safety response times for the entire DTL/CCL vacuum I&C system.
38	Consider reducing the number of vacuum system PLCs	Two different control system architecture schemes were considered during the final design phase. Option A (PDR) required a PLC and independent vacuum system for each DTL tank and CCL module. Option B (to be configured), utilized one PLC for the entire DTL vacuum system and one PLC for the entire CCL vacuum system. Baseded on the weighted design criteria outlined in the SDD (functionality, cost, safety, etc.), and the Linac installation, commissioning, and operation plans,.option A was selected.
39	Insure additional components present in the vacuum be verified by vacuum group	We met with the lead hardware design engineers and reviewed all critical hardware which would impact the vacuum environment (i.e., seal designs on DTL and CCL, beam diagnostic hardware, penetrations, etc.). Design guidelines, based on the vacuum requirements, were developed and supplied to these hardware engineers. In addition, the anticipated gas loads from equipment residing in the vacuum environment (diagnostics, seals, etc.)

		were added to the vacuum models.
40	Recommend using a control box for each RGA head for matching and calibration purposes.	This recommendation has been incorporated. We are working with the SNS ASD to develop an RGA procurement specification which will satisfy the needs of all SNS vacuum systems (one controller per head, 100+ft radiation hardened communication cable, etc.)
41	The issue regarding cable deterioration needs to be clarified, i.e. the provision of extra cables or use of extra cable lengths needs to be evaluated.	The issue of "HV cable deterioration" was evaluated with operational experience from LANSCE and other accelerators. A large database of radiation damage data for various types of cable insulation is well documented in a CERN issued report. This data was used as guidance in selecting vacuum pump and instrumentation cabling that is radiation resistant.
42	A check should be made with the vacuum pump manufacturers regarding the support of large pumps off the flange.	We have already contacted one manufacturer (Varian). Their pumps can be supported via the flanges. If necessary, other manufactures will be contacted to insure that mounting via the flange is acceptable. The support of ion pumps via the attachment flange (without additional support) will be specified in the procurement specifications. The stress induced on the DTL tank and CCL manifold by hanging the ion pumps without any additional support was found to be acceptable.
43	The use of particulate generating components, such as hot filament gauging in the Low Beta (DTL & CCL), are not acceptable due to their contaminating effect on the superconducting section.	The design team reviewed the use of cold cathode gauges rather than hot filament ion gauges on the DTL/CCL vacuum systems. This issue was also raised at the latest SNS vacuum systems meeting in ORNL. The plan is to use cold cathode gauges throughout the linac and storage ring vacuum systems. The lower accuracy of the cold cathode gauge, compared to an ion gauge, will require additional RF conditioning time since the RF vacuum trip point must be set at a more conservative value.
44	Further optimization of the RF window pumping systems needs to be performed. The size and definition of the proposed systems is excessive in its current configuration.	The RF window vacuum system has undergone final design and optimization. We don't agree that the size and definition of the proposed system is excessive. The uncertainty in the RF window conditioning gas load and conductance losses by the RF grills, and outgassing data from LEDA RF window tests indicate that the 1000 L/s NEG pump is required and must be backed with a turbo for conditioning. This RF window pumping system parallels a successful design for the LEDA accelerator. We plan to further back our design choices with RF window outgassing RGA data from the CCL hot model tests in the spring of 2001.
45	The selection of emergency power for the ion pump controllers' needs to be determined.	The back-up electrical requirements for the DLT/CCL vacuum systems have been reviewed. The decision by the ORNL-SNS operations team was to supply UPS only for the vacuum system PLCs and pressure gauge controllers for monitoring the vacuum environment prior to system restart. It is believed that during a power failure, the gas loads to the vacuum environment should be sufficiently small that the pressure will not rise significantly during a power failure in which the vacuum pumps are shut off for several days.
46	A fault tree analysis of the vacuum interlocks needs to be performed to identify failure modes and risk abatement.	A fault tree analysis of the vacuum system and interlocks was created in the final design phase.

2.0 Vacuum System Design

2.1 Vacuum System Layout

The vacuum system equipment layout for CCL module #1 is displayed in the Piping and Instrumentation Diagram (P&ID) of Figure 2.1. The P&ID symbol legend for Figure 2.1 is presented in Figure 2.2. The P&IDs for modules 2 through 4 are contained in Appendix C. As Figure 2.1 indicates, the vacuum system for the main manifold will consist of two turbo pump carts, ten ion pumps, two gas pressurization carts, and a multitude of valves and instrumentation. In addition, Figure 2.1 displays the turbo-assisted Non Evaporatable Getter (NEG) pump assemblies for the RF windows. The details of these vacuum components are discussed in the following sections.

2.2 Valves and Plumbing

As shown in Figure 2.1, pneumatic gate valves have been incorporated in the CCL vacuum design to isolate the turbo/roughing pumps from the vacuum environments. These pneumatic valves will receive compressed air from line sources located in the SNS Linac tunnel. The valves are connected to the vacuum control system PLC for remote control operation and valve positioning status. Pneumatic valves will also be placed along the beam-line before and after modules 1 and 4, respectively, and in the inter-module spacings. These beam-line valves will serve as isolation valves to segregate CCL modules for maintenance and leak checking procedures and will fail in the closed position. Proper global beam-permit controls must be in place to ensure that any power failures that may cause the beam line isolation valves to close also cause the proton beam to trip off. Manual valves will be used in the gas pressurization system to isolate the gas pressurization cart and vent the system to atmosphere if required. All valves will have metal seats and either metal or polymer O-ring seals. The polymer O-rings will adhere to the radiation hardening and leak rates specified in other sections of this report.

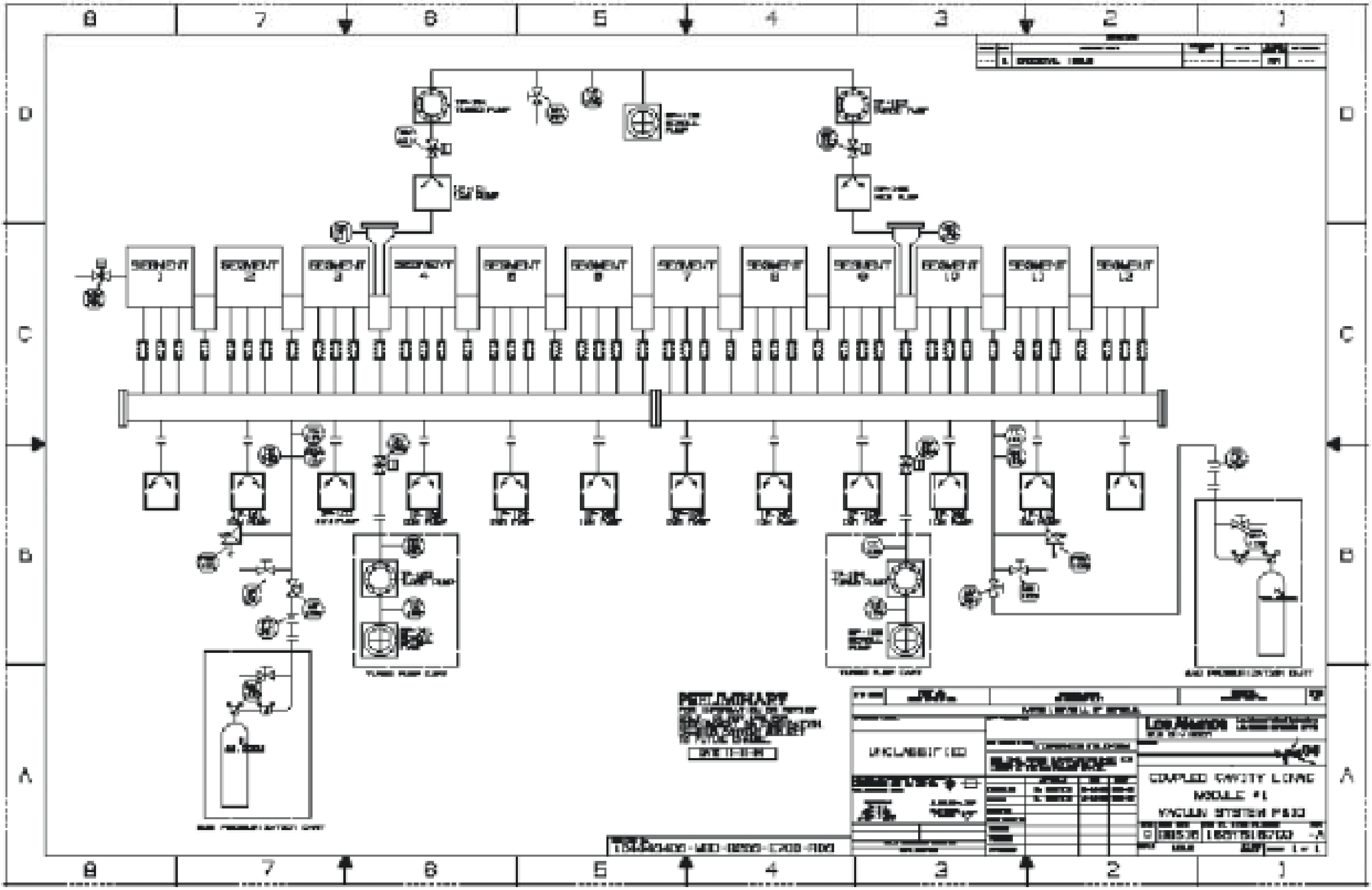


Figure 2.1. P&ID for CCL module #1 vacuum system.

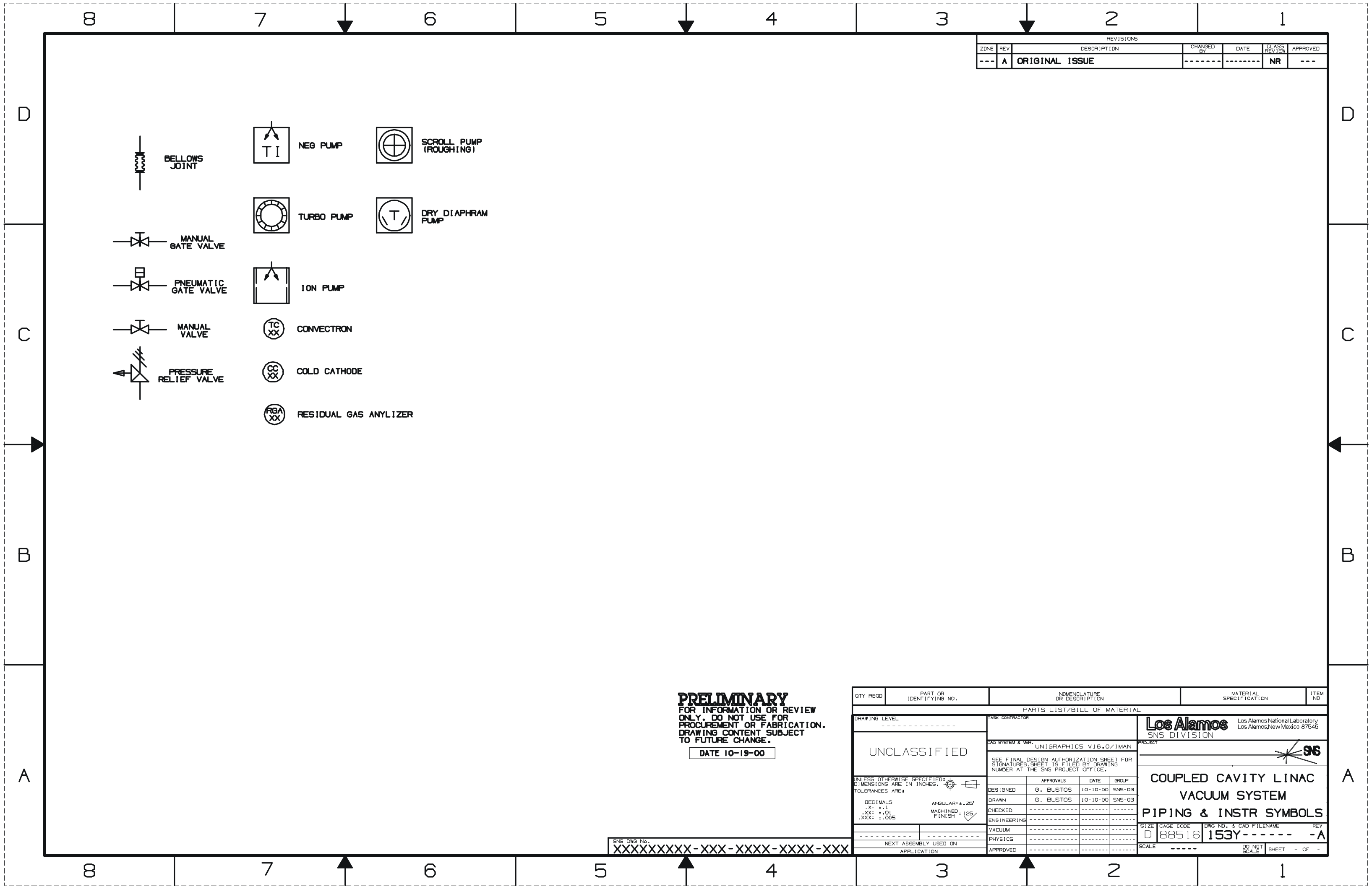


Figure 2.2. P&ID legend for the DTL and CCL vacuum systems.

The remaining vacuum plumbing on the CCLL vacuum system consists of an instrumentation spool piece and a few basic vacuum connectors (i.e., elbows, T's, etc.). All plumbing will be joined with knife-edge sealed flanges.

2.3 Vacuum Seals

Standard metal and polymer vacuum seals are used for all vacuum equipment connections in the CCL. The vacuum seal types, sizes, and quantities for CCL module 1 are displayed in Table 2.1. Similar tables for modules 2 through 4 are contained in Appendix H.

The CCL vacuum system seal designs have been reviewed as part of the CCL Preliminary Design Review and can be found in [2.1].

Table 2.1. Summary of vacuum seal types, sizes, and quantities for CCL module 1.

Seal Name or Location	**Seal Type**	**Qty.**	**Material**	**Nominal Seal Diameter (cm)**	**Seal Thickness (cm)**
Coupling Cavities	"C"	18	Cu	18.62	0.31
Power Coupling Cavities	"C"	4	Cu	18.62	0.31
Beam Tubes	"C"	24	Al	5.75	0.34
RF Window Waveguide	O-ring	2	Al	24.46	0.32
RF Window NEG pump	Conflat	4	Cu	14.73	0.64
RF Window Turbo/Gate Valve	Conflat	2	Cu	3.49	0.32
RF Window Ion Gauge	Conflat	2	Cu	3.49	0.32
Beam Boxes, ends	O-ring	4	Viton	14.29	0.32
Beam Boxes, Diagnostics	O-ring	2	Viton	7.30	0.32

Table 2.2 lists the outgassing and leak rates and loads as well as the total seal gas loads for CCL module 1. Outgas rates were taken from [2.2] while leak rates were obtained from [2.3] and [2.4]. Similar tables for modules 2 through 4 are included in Appendix H. The seal gas loads were incorporated in the vacuum numerical and analytical models discussed in Section 3.

Table 2.2. Summary of vacuum seal outgassing and leak rates for CCL module 1.

Seal Name or Location	Outgas Rate (Torr L/s/cm^2)	Leak Rate (Torr L/s/mm)	Outgas Load (Torr L/s)	Leak Load (Torr L/s)	Total Outgas and Leak Load (Torr L/s)
Coupling Cavities	5.00E-10	3.70E-10	2.60E-07	3.90E-06	4.16E-06
Power Coupling Cavities	5.00E-10	3.70E-10	5.79E-08	8.66E-07	9.24E-07
Beam Tubes	6.00E-10	3.70E-10	1.39E-07	1.60E-06	1.74E-06
RF Window Waveguide	6.00E-10	2.00E-08	4.60E-08	3.07E-05	3.08E-05
RF Window NEG pump	5.00E-10	0	9.23E-08	0.00E+00	9.23E-08
RF Window Turbo/Gate Valve	5.00E-10	0	5.47E-09	0.00E+00	5.47E-09
RF Window Ion Gauge	5.00E-10	0	5.47E-09	0.00E+00	5.47E-09
Beam Boxes, ends	1.14E-08	1.04E-10	1.02E-06	1.87E-07	1.21E-06
Beam Boxes, Diagnostics	1.14E-08	1.04E-10	2.61E-07	4.77E-08	3.09E-07
				Total	3.94E-05

Metal seals will require specific surface finishes on the sealing surfaces. These surface finish requirements, supplied by the seal vendor, will be specified on all engineering drawings of hardware on which these seals are used.

There are several types of polymer materials that can be used for vacuum O-ring seals. Table 2.3 lists the radiation resistance and gas permeability rates of several common O-ring materials. The maximum acceptable cumulative radiation dose limit of 4.3×10^6 Rads (see Section 4 on materials) and a maximum Nitrogen permeability rate (see Section 3 on modeling) of 2×10^{-8} (Std cc cm)/(cm^2 sec bar) limits the acceptable O-ring materials listed in Table 2.3 to Buna, Neoprene, and Viton.

Table 2.3. Radiation and gas permeability rates for various O-ring materials

O-ring Material	**Radiation Dose Limit♣ [Rads]**	**Nitrogen Permeability Rate♣♣ ×10^{-8} [(Std cc cm)/(cm^2 sec bar)]**	**Acceptable Vacuum Seal for DTL/CCL?**
Ethylene-Propylene Rubber (EPR)	8×10^7	7.7 to 29.7	No
Styrene-Butadiene Rubber (SBR)	4×10^7	4.7	No
Acrylonitrile Rubber (Buna-N)	2×10^7	0.177 to 1.89	Yes
Polychloroprene Rubber (Neoprene)	2×10^7	0.1 to 2	Yes
Fluorocarbon (Viton)	1×10^7	0.233	Yes
Silicone Rubber (SIR)	9×10^6	75 to 210	No
Butyl Rubber	2×10^6	1.25	No

♣ See Section 4 for more details on materials. Maximum cumulative dose that materials will be exposed to over 30 years ≈ 4.3×10^6 Rads.

♣♣ Permeability rates obtained from Reference [2.3]. Maximum suggested permeability rate ≈ 2×10^{-8} [(Std cc cm)/(cm^2 sec bar)].

2.4 RF Grills

In order to shield the various vacuum pumps used in the DTL and CCL from RF energy, RF grills were designed. It was determined that slotted RF grills offered the better vacuum conductance over a grill made with holes. One type of grill is located at the mouth of the NEG pump in the RF window vacuum pumping system. No grills were used between the CCL vacuum manifold and the CCL accelerating structure for several reasons. First, the pumping ports between the CCL and manifold are small and little RF energy will get through. Second, the CCL vacuum manifold connects to the accelerator structure through the side coupling cavities and these cavities, in the pi/2 mode, theoretically, do not contain any RF energy.

The calculations that were done on the RF grills utilized the same basic attenuation formula. The RF attenuation equation for the grill is [2.10]:

$$\alpha_g := \left[8.69 \cdot \sqrt{\left(2\cdot\frac{\pi}{\lambda_c}\right)^2 - \varepsilon_1\cdot\left(2\cdot\frac{\pi}{\lambda}\right)^2} \right]\cdot z$$

T. Morino, "Micorwave Transmission Design Data", equation 8-21, page 140

Where λ_c is the cut-off wavelength of the grill and λ is the wavelength of the RF in the accelerating cavity. The dominant mode in a rectangular wave guide is TM10 and the cut-off formula for this mode is

$$\lambda_c := 2 \cdot a$$

where "a" is the width of the wave guide in centimeters. Most of the attenuation takes place in the round nipples that are attached to the grill and supports the pumps. In a round waveguide, the dominated mode is TE11 and the formula to calculate the attenuation is [2.10]

$$\alpha_{sc} := \left[8.69 \cdot \sqrt{\left(\frac{1.841}{\frac{D_s}{2}} \right)^2 - \left[\frac{(2 \cdot \pi)}{\lambda} \right]^2} \right] \cdot L_s$$

T. Morino, "Micorwave Transmission Design Data", equation 7-38, page 120

were Ds is the diameter of the waveguide and Ls is it's length.

The above formulas were used to design the grill geometries as shown in Appendix I. The resulting attenuation of the optimized grills and pipes (nipples) significantly reduces the RF power to well under a watt (see Appendix I for complete calculations). The power that reaches the NEG pump in the RF window is about 4 milliwatts.

The combination of a slotted grill RF shield and a pipe or nipple of sufficient length greatly reduces the RF power that reaches the NEG pumps in the CCL to negligible levels. No problems due to RF power effecting the vacuum pumps are foreseen.

2.5 Vacuum Pumps

To achieve the pumping requirements of the CCL and maintain a simplistic design approach, a distributed vacuum pumping system was chosen in which the main vacuum pumps were distributed along a vacuum manifold beneath the CCL segments. Mounting pumps in this fashion resulted in a high conductance loss between the pumps and vacuum environment but did not require the use of RF shields across the pump ports.

As shown previously in Figure 2.1, a combination of roughing, turbo, ion, and Non Evaporatable Getter (NEG) pumps were chosen for the CCL vacuum system. Each CCL module is equipped with two 300 L/s turbo/scroll pump cart ports and ten 300 L/s ion pumps. Two additional ion pump ports are provided on the manifold in the event that additional pumping is required. A portable turbo/scroll pump cart was selected for pumping the CCL module from atmospheric pressure, down to a pressure (>10-5 Torr) that the main ion pumps can be turned on. The portable turbo/scroll pump cart is a temporary pumping system to be used during the early vacuum and RF conditioning of the CCL module. The high pumping speed and flow through design makes the turbo pump ideal for conditioning the SNS linac. Upon completion of the conditioning stages, the turbo/scroll pump cart will be removed and be made available for other vacuum system operations. A pneumatic isolation valve will be placed on the CCL vacuum manifold to allow for attaching and removing the turbo pump cart without impacting the vacuum environment. A dry scroll pump was chosen over a piston pump for roughing and turbo pump backing operations. A detailed design report that addresses this comparison study is contained in Appendix F. There has been some concern about contamination of forelines caused by particulates from scroll pumps. Particulates are generated by scroll pumps during normal operation due to the PTFE seals on the vane tips moving against their sealing surfaces. Varian Product Information bulletin #194S discusses proper isolation and venting of scroll pumps to prevent scroll pump generated particulates from reaching the turbo pump.

Ion pumps were selected to maintain the base pressure during the lifetime of the linac, mainly because of their high pumping speed, lack of moving parts, low cost, and high reliability for long-term operation. The pump size was chosen to be the largest that could be interfaced with the selected ports, while still remaining as an “off-the-shelf” item. The number of ion pumps was determined by inspection from a plot of average beamline pressure versus ion pump quantity for a single CCL module, as presented in Section 3 of this report. In the unusual event of failure of an ion pump, the outgassing from the pump is insignificant for pressures above 10^{-10} Torr. Because of the low risk of ion pump failure, combined with the low outgassing rate of the pump components and extra pump capacity, ion pump isolation valves were not incorporated in the design.

As mentioned previously, the narrow opening, or iris, that exists between the CCL bridge coupler and its associated RF window, prevents the main module vacuum pumps from effectively evacuating the waveguide transition piece between the iris and the RF window. In addition, the RF window is predicted to have a large outgassing rate of 5×10^{-8} Torr Liter/s/cm^2, much of which is hydrogen and water vapor, during the early stages of RF conditioning [2.4]. The high RF window gas load, in combination with a minimal spatial allotment for vacuum hardware and supports around the RF window, required the use of a special vacuum pump. The design criteria of high pumping speed (especially for hydrogen), lightweight, minimal vibrations, and a small spatial envelope, led to the selection of a Non Evaporable Getter (NEG) pump. This pump is extremely compact and lightweight in comparison to ion pumps of equivalent pumping capacity. In addition, the NEG pump has an extremely high pumping speed for hydrogen. The details of one such NEG pump (SAES CapaciTorr-B 1300-2) are shown in Figure 2.3(a). A NEG pump has been in successful operation on the Low Energy Demonstration Accelerator's (LEDA) RFQ RF window at Los Alamos National Laboratory [2.5], see Fig. 2.3(b), and was also selected for the LEDA's Coupled Cavity Drift Tube Linac RF window vacuum pumping system [2.6]. For the SNS CCL, the NEG pump will be mounted directly to the RF transition waveguide assembly to maximize the conductance. An RF grill will be placed across the pump port to attenuate RF fields and prevent RF excitation of the pump housing.

(a)

(b)

Figure 2.3. (a) Photo and schematic of an SAES CapaciTorr®-B 1300 NEG pump and (b) NEG pump installed on LEDA R F window.

The longevity of the NEG pump for this vacuum application, the need for high conductance between the pump and waveguide, and the motivation to reduce hardware cost and control system complexity, have resulted in an omission of an isolation valve between the NEG pump and waveguide.

One drawback of the NEG pump is that it cannot pump inert gases. To overcome this limitation, a small turbo pump (70 L/s) was added to the RF window pumping system. This turbo pump also provides for initial and periodic vacuum conditioning of the NEG pump. Space and clearance limitations required that the turbo pump be mounted on the housing of the NEG pump. A pneumatic isolation valve was placed between the NEG and turbo pumps to allow for shutting down of the turbo during steady state operation of the Linac. A dry scroll was chosen to back the RF window turbo pump. To isolate the vacuum pumps from the RF energy in the waveguide transition piece, RF shields were positioned across the vacuum hardware ports. The arrangement of the complete RF window vacuum system is noted in Figure 2.4.

The CapaciTorr-B 1300 uses ST185, a sintered NEG material in the form of a blade. Two cartridges within the NEG pump housing, hold multiple NEG material blades. A concern has been raised that a small number of the NEG particles on the blade surface may not bond well during the sintering process and may fall off, creating dust particles. Operational experience on the LEDA RF window vacuum system showed no signs of loose particulates when the system was disassembled for reconfiguration in May 1999.

The CapaciTorr-B 1300 is initially shipped from the factory with a passivating layer, made up of physisorbed gases that form external monolayers covering the surface of the NEG material. The gases are H_2, H_2O, CO, CO_2 and CH_4. Before the NEG pump can be utilized, the passivating layer must be removed by heating the getter material to a temperature of 450°C. During this activation stage, the passive layers are desorbed from the surface of the NEG's getter material and drawn out of the vacuum environment by the small turbo pump. During activation or regeneration, the heat from the NEG will drive off other gases from the surrounding walls, which the turbo pump will also remove from the vacuum environment.

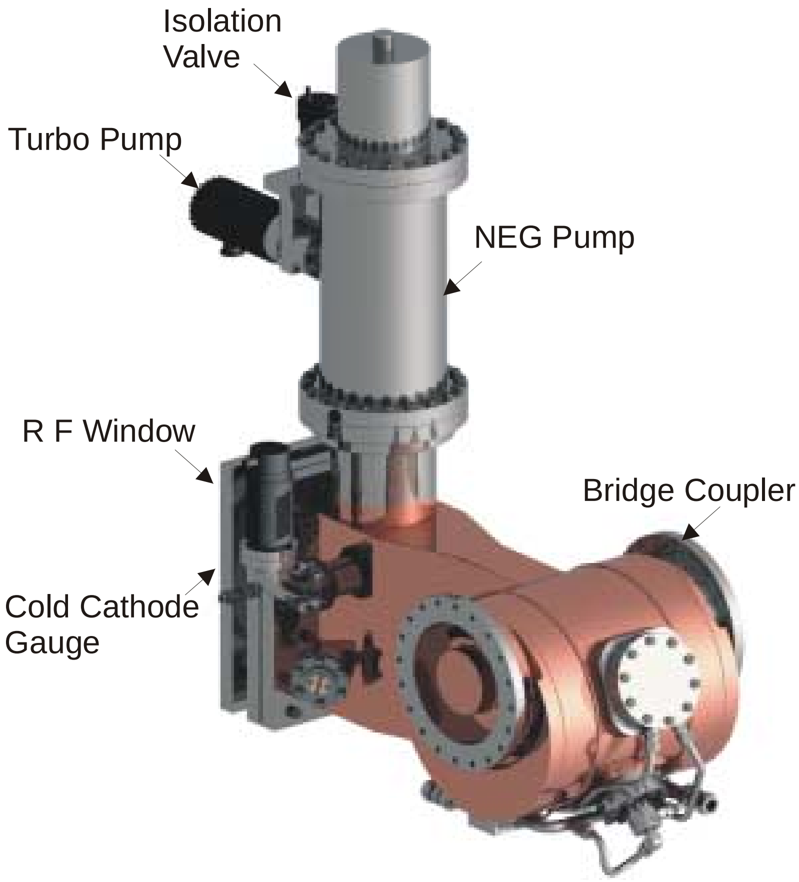


Figure 2.4. Details of the CCL RF window vacuum pumping assembly.

Under normal vacuum operation without a vent to atmosphere, the NEG will pump active gases and some of the gas molecules will gradually form another passivating layer, requiring that the NEG be eventually regenerated. Regeneration also occurs at a temperature of 450°C. Note that NEGs can only pump hydrogen reversibly and all other active gas molecules are diffused further into the bulk getter material during regeneration.

There is some concern that the gases given off during activation or regeneration could contaminate the RF window or waveguide transition segment. As stated before, the gases desorbed during activation are H_2, H_2O, CO, CO_2 and CH_4. During subsequent regenerations without an air vent, NEGs can only give off hydrogen. Other gases that are desorbed from the walls of the pump due to the elevated temperature should be minimal with proper high vacuum fabrication and handling techniques. The gas molecules desorbed from the wall of the pump body may stick and form monolayers on the RF window or waveguide transition segment. These monolayers will be easily and quickly driven off by the RF and should not impact RF operations.

Mechanical, operational, and electrical specifications for all of the vacuum pumps are contained in Appendix E.

2.6 Instrumentation

The CCL vacuum system design requires a means to monitor the vacuum pressure for system operation and provide vacuum safety interlocks to the LLRF and SNS Global Control Systems. Although vacuum pressure can be derived from ion pump current, there is a need to measure vacuum pressure before the ion pumps are started. An ion pump requires a moderately high vacuum (approximately $1x10^{-5}$ Torr) to be established by the turbo pump cart before it can be started. Starting an ion pump at higher pressures causes the pump to overheat or generate internal electrical discharges and reduces the pump's operating life. In addition, SNS global control operations require continual monitoring of vacuum pressures, especially in the event of an electrical power failure. It is much more cost effective to provide UPS power to a set of vacuum gauge controllers than to ion pump controllers to monitor system pressure in the event of an electrical power failure. Consequently, to provide the most robust control system, an independent set of gauges is required to monitor the status of the CCL vacuum environment.

Two convectron gauges will be used per CCL vacuum manifold. A convectron is used to measure pressure from atmosphere down to the milliTorr range. A convectron gauge is more accurate than a thermocouple gauge or Pirani gauge since it has a temperature compensated heat sensor and precisely controls the power delivered to the heating element.

Three additional convectron gauges will be used to monitor the foreline pressure of each of the turbo pumps. These gauges will provide interlocks to the PLC to protect the turbos from high foreline pressures.

Four cold cathode gauges per CCL module will be used to monitor operating vacuum pressures (10^{-3} to 10^{-9} Torr). Two cold cathode gauges will be mounted on the instrumentation spool pieces of the vacuum manifold and will monitor module pressures. These gauges will provide vacuum system monitoring and provide interlocks for turning on/off the ion pumps and the RF power. One cold cathode gauge will be mounted on each RF window waveguide transition and will monitor system pressure in the vicinity of the RF window. This gauge will provide a safety interlock signal for the LLRF controls.

The SCL requires a particulate-free environment to minimize electron discharges and quenching of the super-conducting cavities. Consequently, ion gauges were ruled out for vacuum measurements in the DTL and CCL because of their potential to generate particulates. In addition, the environment in the storage ring required the use of cold cathode gauges rather than ion gauges. In order to limit the number of gauge types in the SNS vacuum systems and satisfy the minimal particulate generation requirements of the SCL, cold cathode gauges were selected for high vacuum pressure measurements in the CCL. The standard accuracy of the cold cathode gauge (≈ 50%) is significantly less than an ion gauge (5-10%). Consequently, the RF trip vacuum levels will need to be set at a more conservative value (10^{-6} Torr) with the cold cathode gauge.

A quadrupole type Residual Gas Analyzer (RGA) with an electron multiplier and an atomic mass unit range of at least 0 to 100 will be required to measure the partial pressure of gas species in the CCL vacuum system. The RGA is an effective tool to monitor for vacuum system leaks, check for surface contamination such as oils and residues left over from the manufacturing and assembly processes, and observe the various gas species within the vacuum environment. The high levels of radiation in the linac tunnel requires that only the RGA's quadrupole head can be mounted to the CCL vacuum manifold. The RGA controller will need to be remotely mounted in the vacuum control system's electronics rack, located in the klystron gallery. This will require an approximate 100 ft. power and communications cable to be run from the RGA controller to the quadrupole head.

2.7 Controls

Each CCL module is being designed to have its own vacuum control system. This design choice was made to allow each CCL module to be vacuum leak checked, conditioned, operationally certified, and operated and maintained on an individual basis. This control system segregation is also consistent with the CCL water cooling and resonance control systems [2.7] and the CCL assembly and installation plans.

The control system for the CCL vacuum will consist of a local control system that can operate in a stand-alone mode or be connected via a network to the SNS global control system running under EPICS. The stand-alone mode will be used for initial testing and commissioning. This mode will also be useful after commissioning in the event EPICS is not running.

The local control system will be implemented using an agreed-upon SNS project standard Allen Bradley ControlLogix Programmable Logic Controller (PLC) that monitors and controls all of the individual vacuum pump and instrumentation controllers. The PLC will be programmed with Allen Bradley's RSLogix5000 ladder code programming toolkit. A local touch screen operator interface terminal will be provided for local display of the instrumentation and system operation. A password-protected screen will allow operators to access the control system parameters to make changes if needed, as well as provide manual control of the vacuum pumps and instrumentation. The PLC will also be connected via Ethernet to an IOC and the SNS Global Controls system.

An equipment rack will be provided that complies with the SNS rack standards. The rack will contain the vacuum pump and instrumentation controllers, the ControlLogix system, the PanelView operator interface, power supplies, terminal blocks, and a cooling fan.

Additional details of the control system can be found in Section 5 of this report.

2.8 Gas Pressurization and Relief

The CCL vacuum system must be equipped with a clean gas handling system to allow the CCL vacuum environment to be pressurized back up to atmospheric pressure during maintenance procedures in which the vacuum seal must be broken. The gas handling system must also provide as a pressure relief mechanism to prevent over-pressurization of the CCL segments.

Figure 2.5 displays the gas pressurization and relief system that has been designed for the CCL vacuum system. A dry Nitrogen gas bottle (99.999% N_2) serves as the pressurized gas source, used to fill the CCL vacuum volume. Dry nitrogen will be used to purge the CCL vacuum system during vacuum shut-down or CCL maintenance procedures so that the interior surfaces of the vacuum remain as clean and moisture free as possible. Two gas pressure regulators (coarse and fine), connected to the outlet of the N_2 gas bottle, were incorporated to step down the gas bottle pressure from several thousand psig, to less than a single psig. A manual isolation valve separates this part of the gas pressurization system from the CCL vacuum environment. On the vacuum side of the isolation valve, an orifice plate gas throttling mechanism has been incorporated to limit the gas flow rate out of the gas bottle. Next to the orifice plate is a pressure relief valve, which has been designed to crack at 1 to 2 psig and thus limit the amount of pressurization of the CCL module. Internal pressure limits for the DTL and CCL were calculated in order to determine safe operating pressures for the nitrogen purge subsystem. Finite element modeling of the CCL components subject to internal pressure loads was completed [2.12]. The limiting component for the system with respect to internal pressure was identified and the specific pressure at which yielding initiates was calculated. The calculated internal pressure limit for the CCL is 50.3 psig. The limiting CCL component is the end cell wall. The nitrogen purge system design operating pressure is less than 2 psig and the over pressure relief valve setting will be 1 to 2 psig. Considering the calculated internal pressure limits, the purge system design provides ample protection against internal over-pressurization.

To correctly size the orifice plate and pressure relief valve, an orifice plate restrictive gas flow study by Shrouf [2.8] was referenced. As a basis for this analysis, a determination was made to not allow the accelerator tanks to be pressurized above 2 psig when backfilling with dry nitrogen. A pressure relief valve that met this requirement was the one inch CTI-Cryogenics PRV supplied by Scientific Sales [2.9]. A performance graph of this valve is shown in Figure 2.6. Notice that this graph displays an "original" design and an "improved design". The improved design was selected for the CCL vacuum system. Using the improved valve's performance curve of Figure 2.6, it is seen that this pressure relief valve will allow about 13 SCFM flow rate at a cracking pressure of 2 psig pressure in the modules.

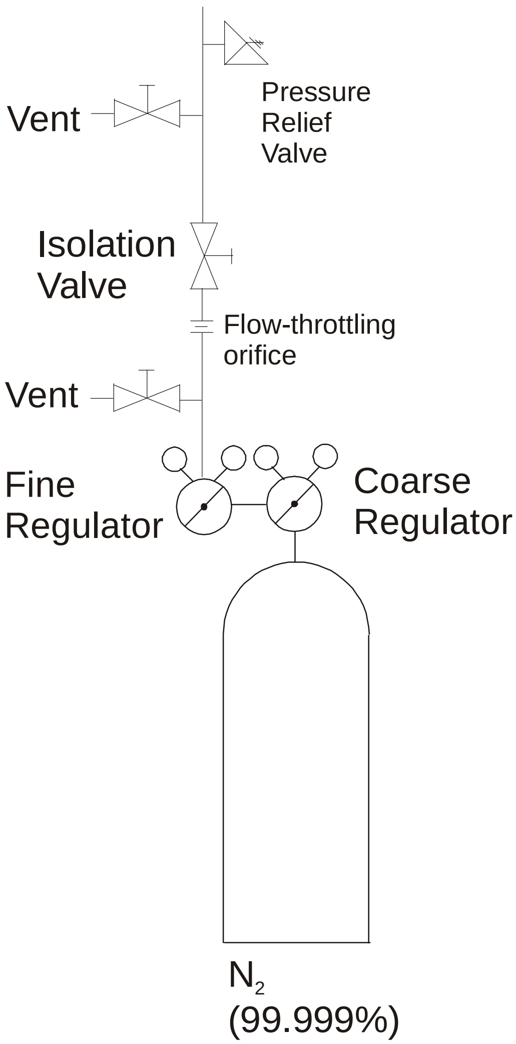


Figure 2.5. CCL gas pressurization system.

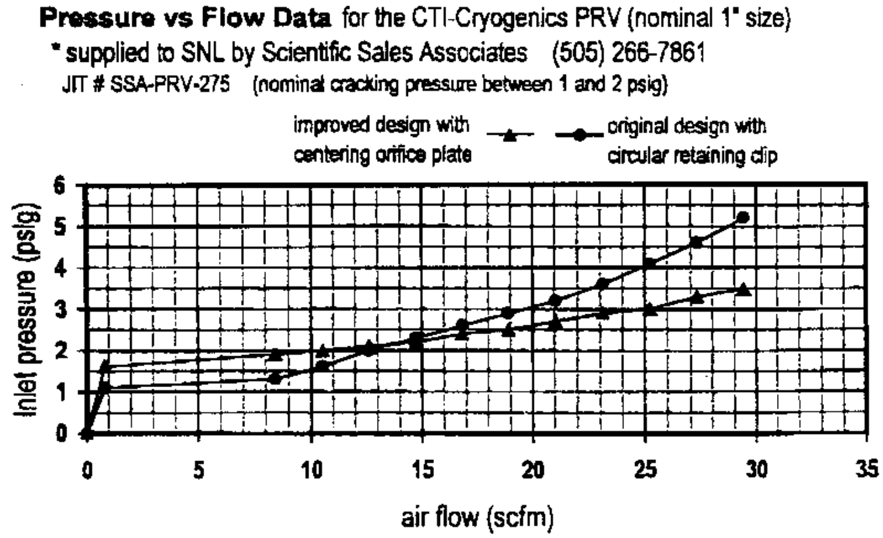


Figure 2.6. Performance curve of the CTI-Cryogenics PRV.

A standard nitrogen bottle holds about 220 standard cubic feet of gas under a pressure of 2,000 to 2,200 psig. To determine the orifice size necessary to hold the flow rate to about 13 SCFM, Table 1 of [2.8] was referenced. In that Table, a 0.020 inch inner diameter orifice, and 1997 psig gas bottle will allow about 13.5 SCFM flow rate of air. At this flow rate, it will take about 6 minutes to backfill a single CCL module, which have a volume of about 60 cubic feet.

The data taken in the SNL paper is relevant to a specific orifice design. One can not drill out a blank cylinder and expect it will perform as expected. The restrictive orifice that was used in the calculation, and that used for the actual CCL vacuum system, should be in agreement with Table 1. For a more detailed discussion of these calculations, see Appendix I.

Finally, manual vent valves have been included as a means to vent any part of the gas pressurization system to atmosphere, should it be required. The gas handling system will attach to a conflat flange port on the CCL vacuum equipment spool piece. It is anticipated that the portion of the gas handling system upstream of the gas throttling device (refer to Fig. 2.5), will be mounted on a portable cart, and will thus be available to service all SNS vacuum systems.

3.0 Vacuum System Analyses

3.1 CCL RF Structure Vacuum Model

3.1.1 Design Goals and System Description

The primary requirement for the CCL vacuum system is to provide sufficient pumping to overcome the surface outgassing of vacuum facing components, the leak and outgassing rate of seals, and maintain a sufficient beamline pressure. The vacuum requirements for the CCL, given in Table 3.1, were determined from calculations involving the stripping of the proton beam by gas molecules in the vacuum environment [1.6]. When the H^- beam is present, the CCL beamline pressure must be kept below 8.9 x 10^{-8} Torr [1.3] when pressures are averaged over 5 meters of beamline. This pressure limit applies to a beam energy of 185 MeV, , but was applied to all four CCL modules in which the beam energy ranges from 86 MeV to 185 MeV. This pressure is the maximum recommended to reduce scattering of the H^- beam, and associated activation of the CCL hardware by limiting the radiation dose to 10 mrem/hr one foot from the module 4 hours after shutdown following a 100 consecutive day run. In the numerical model, a design goal of 4.4 x 10^{-8} Torr was sought for the average CCL beamline pressure in order to have an operating margin of two. Thus, the pumps were sized to achieve an operating base pressure of at least 4.4 x 10^{-8} Torr for a reasonable gas mixture. It was found that using a gas mixture in the numerical model, as will be discussed below, produces pressure that is lower than that obtained for “air” as the gas medium (with a composite mass of 28.98 amus). Consequently to minimize the complexity of the analysis, a design goal for an operation base pressure of 4.5 x 10^{-8} Torr was sought using air as the gaseous medium. Finally, an additional goal of maintaining a base pressure of 8.9 x 10^{-7} Torr in the event that one ion pump failed, was defined.

TABLE. 3.1. CCL Vacuum System Requirements and Values specified by SNS for beam energies between 87 and 185 MeV.

Parameter		Requirements / Value
Pumping to overcome system outgassing		1.0x 10^{-10} Torr-L/sec/cm^2 for SS and Cu (at 100 hrs: post-cond.) 2.5 x 10^{-9} Torr-L/sec/cm^2 for all (at 100 hrs: pre-cond.)
Beamline pressure Post - rf conditioned Normal: all ion pumps on	Design Required	8.9 x 10^{-8} Torr (avg.) for mixed gases < 4.4 x 10^{-8} Torr for mixed gases
Beamline pressure Post - rf conditioned Failure : all but 1 ion pump on	Design Required	8.9 x 10^{-8} Torr (avg.) for mixed gases < 8.9 x 10^{-8} Torr for mixed gases

Turbo and scroll pumps, mounted on a portable cart, have been chosen for roughing down the vacuum environment and providing initial vacuum conditioning of the CCL. These pumps are used to lower the pressure below 10^{-5} Torr, after which ion pumps, used for steady-state vacuum pumping of the CCL, can be turned on. Ion pumps were chosen for steady-state operation because of their reliability and lack of the need for a backing pump.

The surface outgassing rate of the annealed OFE copper is assumed to reach 1 x 10^{-10} Torr-L/s/cm^2 after 100 hours of vacuum and RF conditioning. This rate is based on measurements from the APT/LEDA CCDTL Low Beta Hot Model [2.6]. It is also consistent with measurement results from SLAC/B-Factory (see Appendix A). To achieve this outgassing rate, rf power is turned on to provide surface heating and molecular excitation to drive out trapped and adsorbed gases. During vacuum conditioning, the turbo pumps and ion pumps can be used to maintain 10^{-6} Torr until conditioning is complete and the outgassing rate drops to the post-conditioning outgassing rate. In the DTL vacuum modeling, a steady-state outgassing rate of 1 x 10^{-10} Torr-L/s/cm^2 was assumed after 100 hours of vacuum and RF conditioning. In order to meet the design goal of the pressure of 4.4 x10^{-8} Torr in the CCL, the Cu 100-hr outgassing rate must be less than or equal to 8 x 10^{-11} T-L/sec-cm^2. The results for the case of 1 x 10^{-10} T-L/sec-cm^2 are also presented in this report for comparison. It is very important to notice that the difference between these pressure values is nearly negligible, taking into account of the effect of other more critical parameters such as cleaning and operation temperature. Table 3.1 summarizes many of the vacuum system design requirements.

Figure 3.1 shows a 3D drawing of the CCL and its manifold and optimized pumping configuration. A description of components to be evacuated along with the optimized pumping system is provided in Table 3.2.

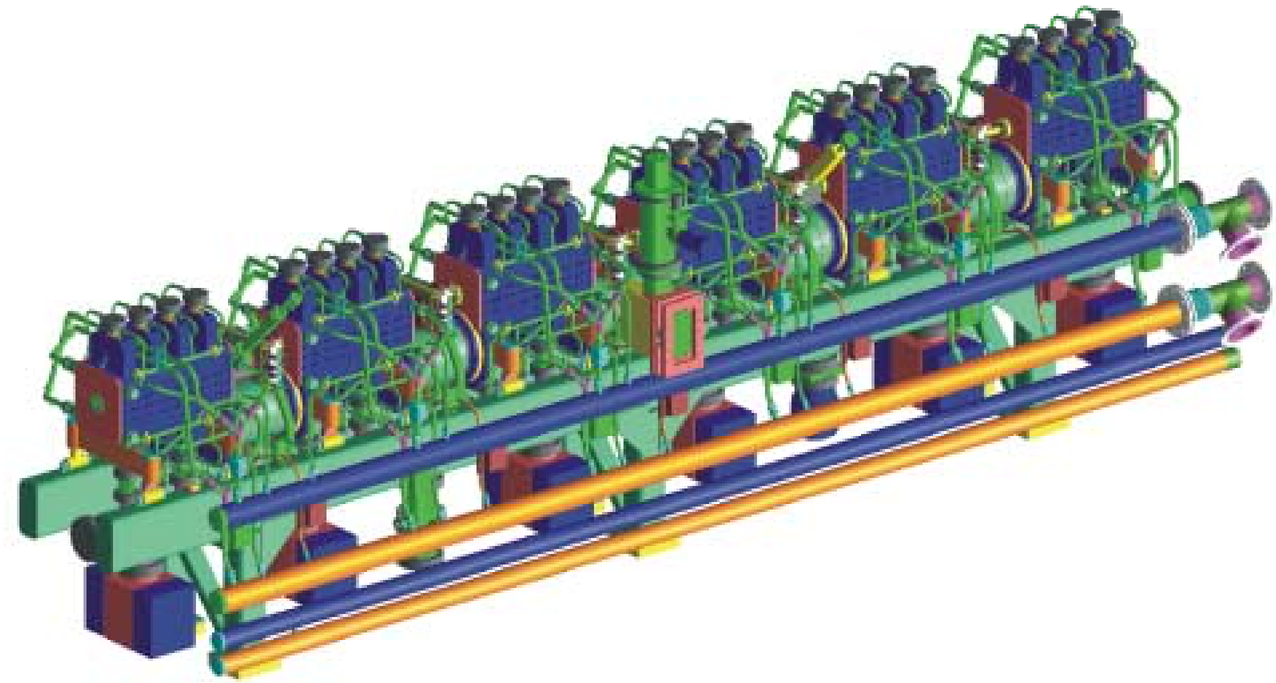


FIGURE 3.1. Six segments of CCL Module 1 with optimized pumping configuration for a 5.6-meter long, 6” dia. Manifold.

TABLE 3.2. One 5.63-meter length of CCL Module 1 (representing 1/2 of a typical module out of the CCL Mods. 1-4) and optimized vacuum system.

CCL Module 1
OFE Copper, hydrogen brazed - 11.3 m
8 cells/segment, 12 segments
Two stainless steel manifolds attached to 2 pump carts (1 roughing and 1 turbo pump) and 10 ion pumps
Pumping system per manifold (5.63 meters)
One PTS 300 dry scroll roughing pump (5 L/s nominal)
One V300 turbo pump (300 L/s nominal)
Five Physical Electronics Captorr 300 conventional ion pumps (300 L/s nominal)
One 6-inch gate valve for turbo pump
Detailed system parameters for one manifold
Total copper surface area = 159,918 cm^2
Total stainless steel surface area (manifold) = 40,457 cm^2
Total volume = 531 L
Total final gas load = 1.8 $x10^{-5}$ Torr-L/sec (assumes Cu outgassing rate for Cu of 8 x 10^{-11} Torr-L/s/cm^2 and for stainless steel of 1 x 10^{-10} Torr-L/s/cm^2
Total seal leak and outgassing rate = 8.7 x 10^{-7} Torr-L/sec (5% of total gas load)
Average beamline pressure after pumping air with 5 ion pumps (normal mode) = 4.04 x 10^{-8} Torr
Average beamline pressure after pumping air with 4 ion pumps (failure mode) = 5.00 x 10^{-8} Torr

3.1.2 Numerical Model Description

The numerical model of the vacuum system models the gas load balance between half of a CCL module, including the cavities, short coupling cells, bridge couplers, all associated seals, and the vacuum hardware. A half module was chosen to take advantage of symmetry conditions and minimize the computation effort. In addition, the length of a half module is approximately 5.6 meters, which is the longest recommended length for manufacturing and handling the vacuum manifold. Figure 3.2 shows the model representation of the 6 segments (half of a module), bridge couplers, beam tubes, vacuum manifold, bellows, vacuum pumps, and the interconnecting conductances. In all, the model is divided into 182 sub volumes and interconnecting conductances (in the molecular flow regime).

The RF window system was not included in this model because the coupling conductance through the iris between the RF window waveguide transition region and the main CCL vacuum environment is less than 10 L/s. This minimal conductance required a separate vacuum pumping system for the RF window environment. A detailed vacuum model was developed to size the RF window vacuum system and is described in the next section of this report.

Pressure history is studied by solving the coupled gas load equations between all the sub-volumes. A summary of the features in the code is presented in Table 3.3. Details of these features are discussed in the following subsections.

TABLE. 3.3. Features of the CCL vacuum system numerical model.

Features of Numerical Model
Solves entire transient pumpdown curve
Separate time-dependent outgassing rates for conditioned copper and stainless steel surfaces
Pressure-dependent pumping speeds for all three pump types
Automatic distribution of pumps for parametric studies
Automatic selection of appropriate gate valve sizes with each pump size
Inclusion of seal permeability and outgassing rates independent of time
Flag for air, H_2, H_2O, N_2, or CO_2 analysis to choose proper pump speeds and conductances
Pressure solved for 182 sub-volumes
Written with Mathematica [3.1] and runs in 20 seconds on a 266 MHz Power Mac G3

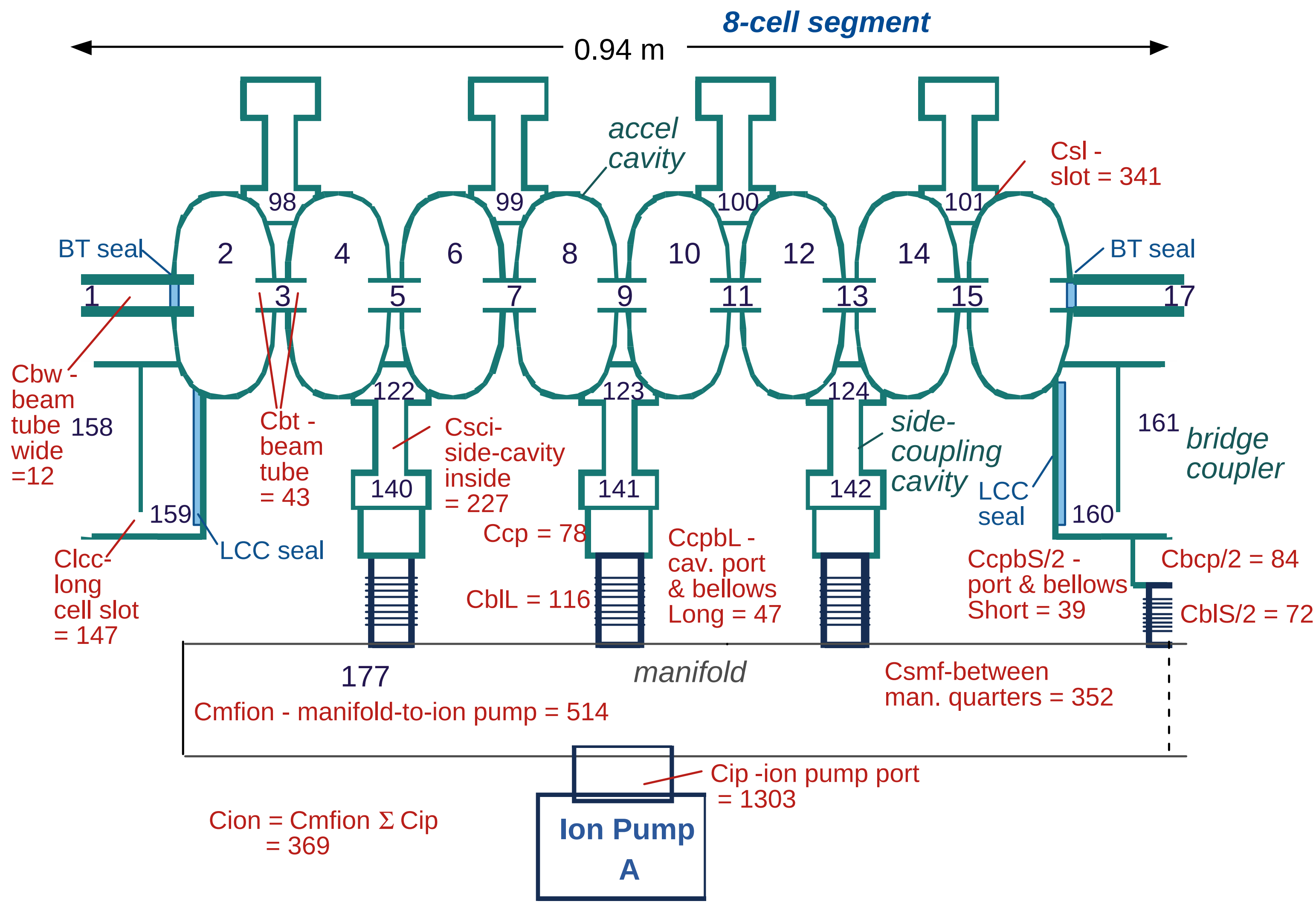


FIGURE 3.2.A. Layout of 1st of 6 segments of sub-volumes and conductances in the model of the SNS/CCL.

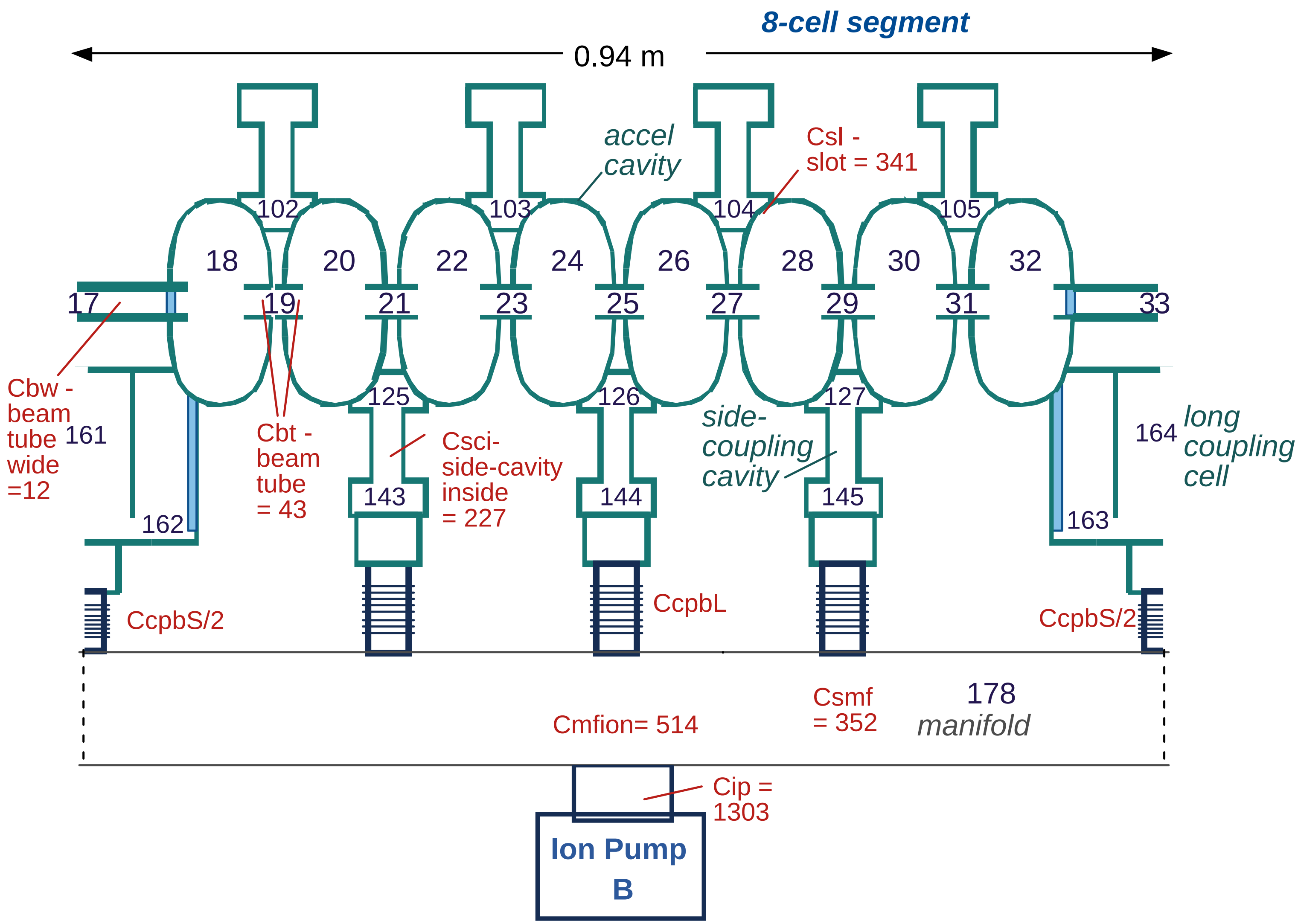


FIGURE 3.2.B. Layout of 2nd of 6 segments of sub-volumes and conductances in the model of the SNS/CCL.

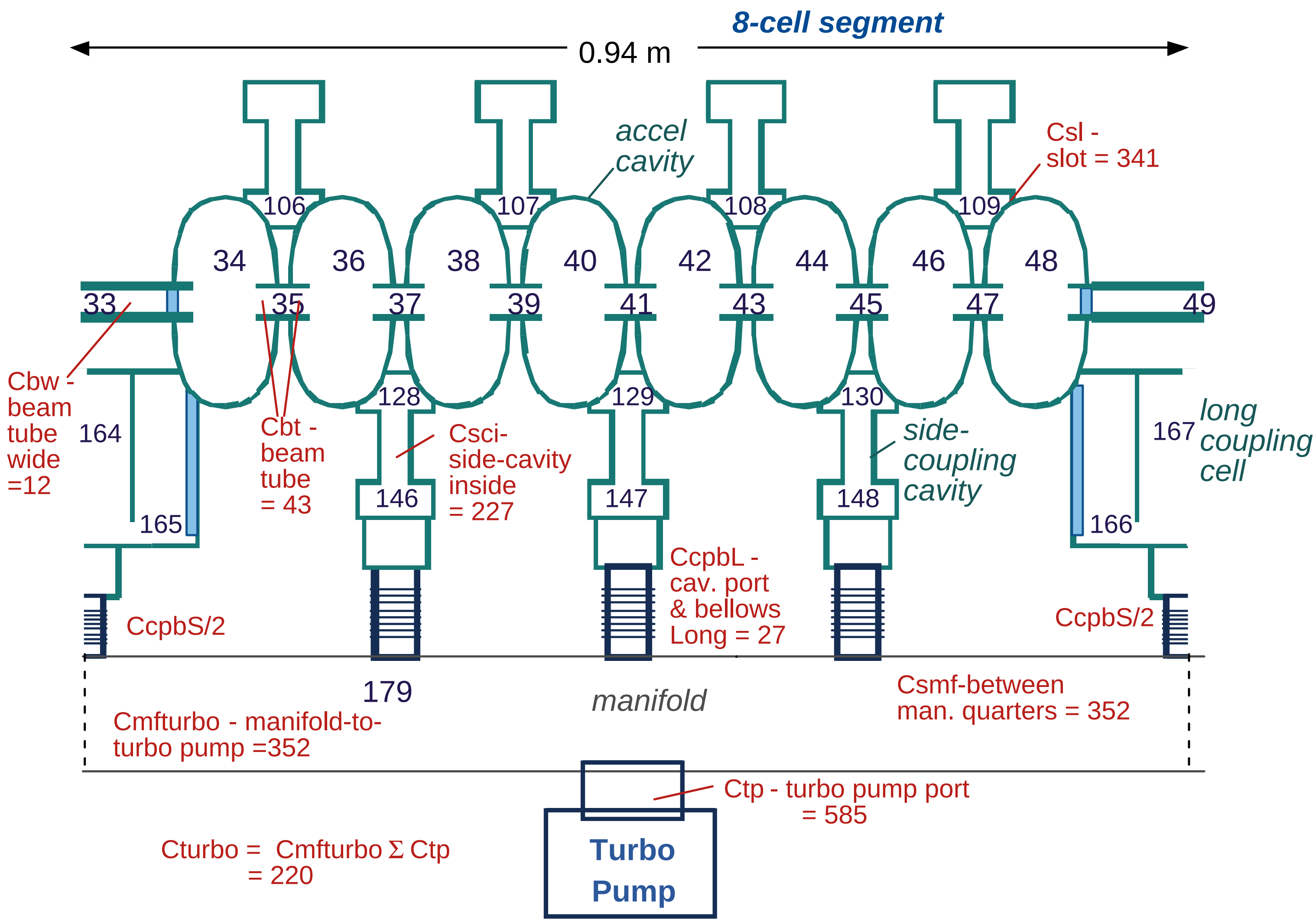


FIGURE 3.2.C. Layout of 3rd of 6 segments of sub-volumes and conductances in the model of the SNS/CCL.

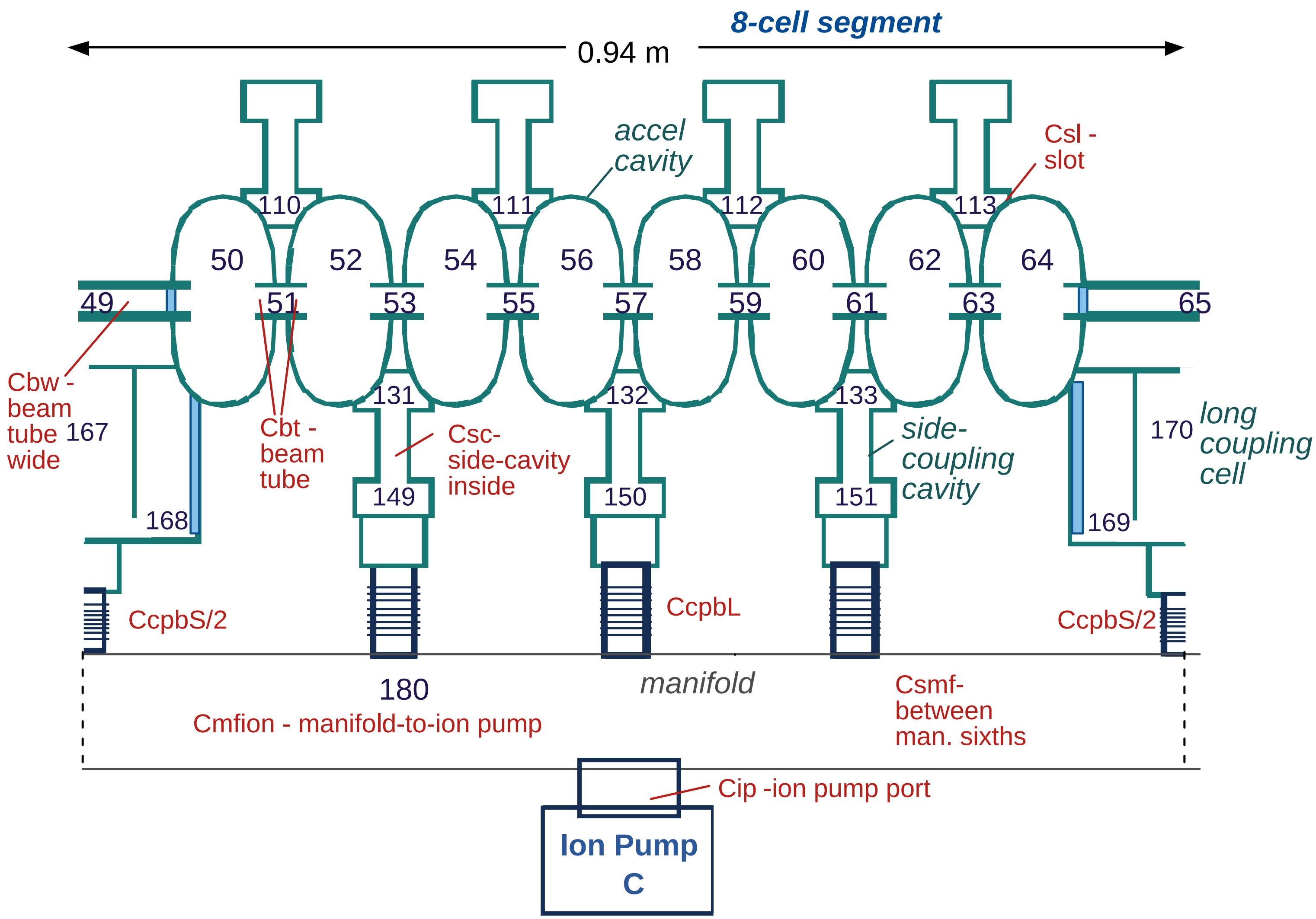


FIGURE 3.2.D. Layout of 4th of 6 segments of sub-volumes and conductances in the model of the SNS/CCL.

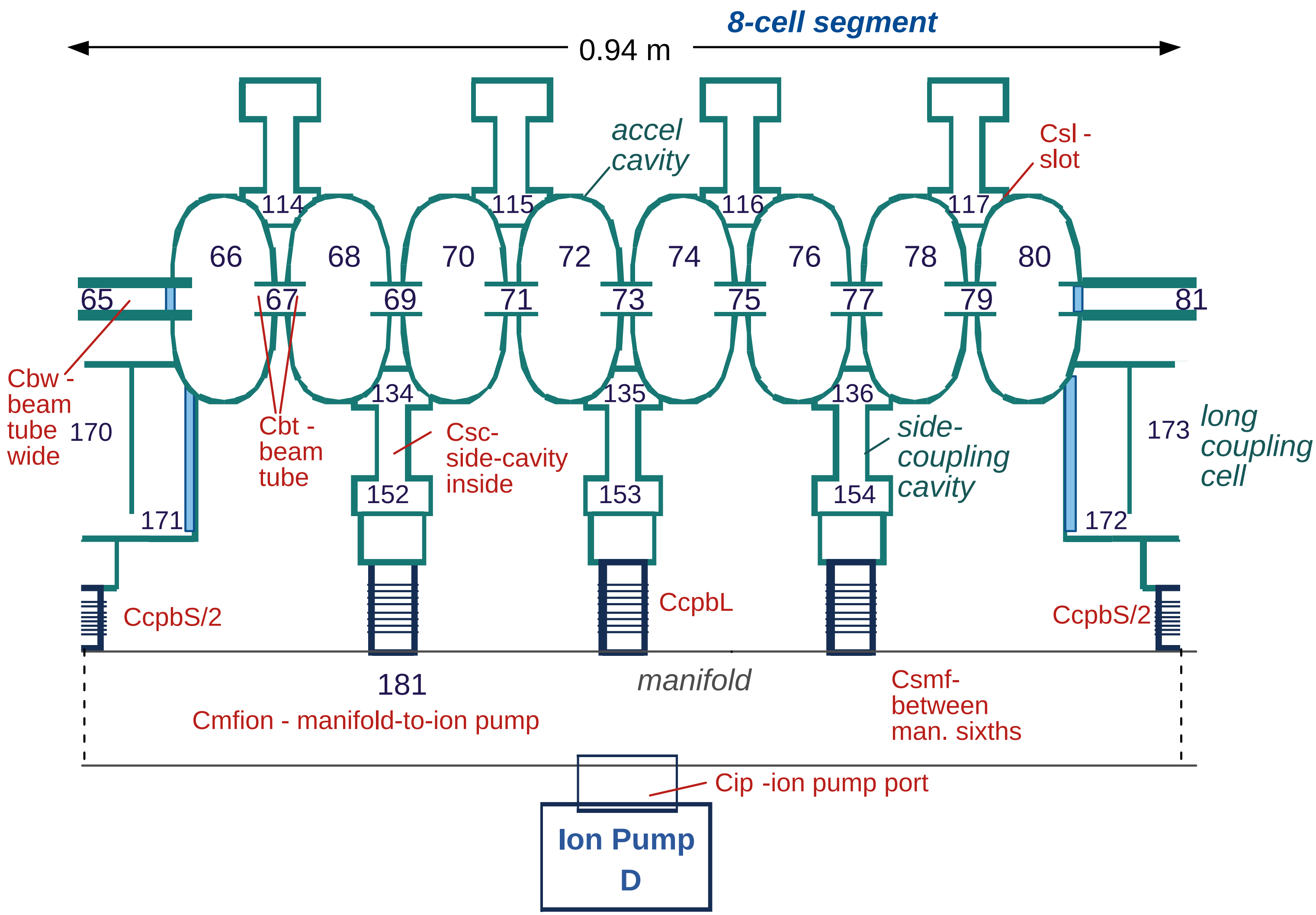


FIGURE 3.2.E. Layout of 5th of 6 segments of sub-volumes and conductances in the model of the SNS/CCL.

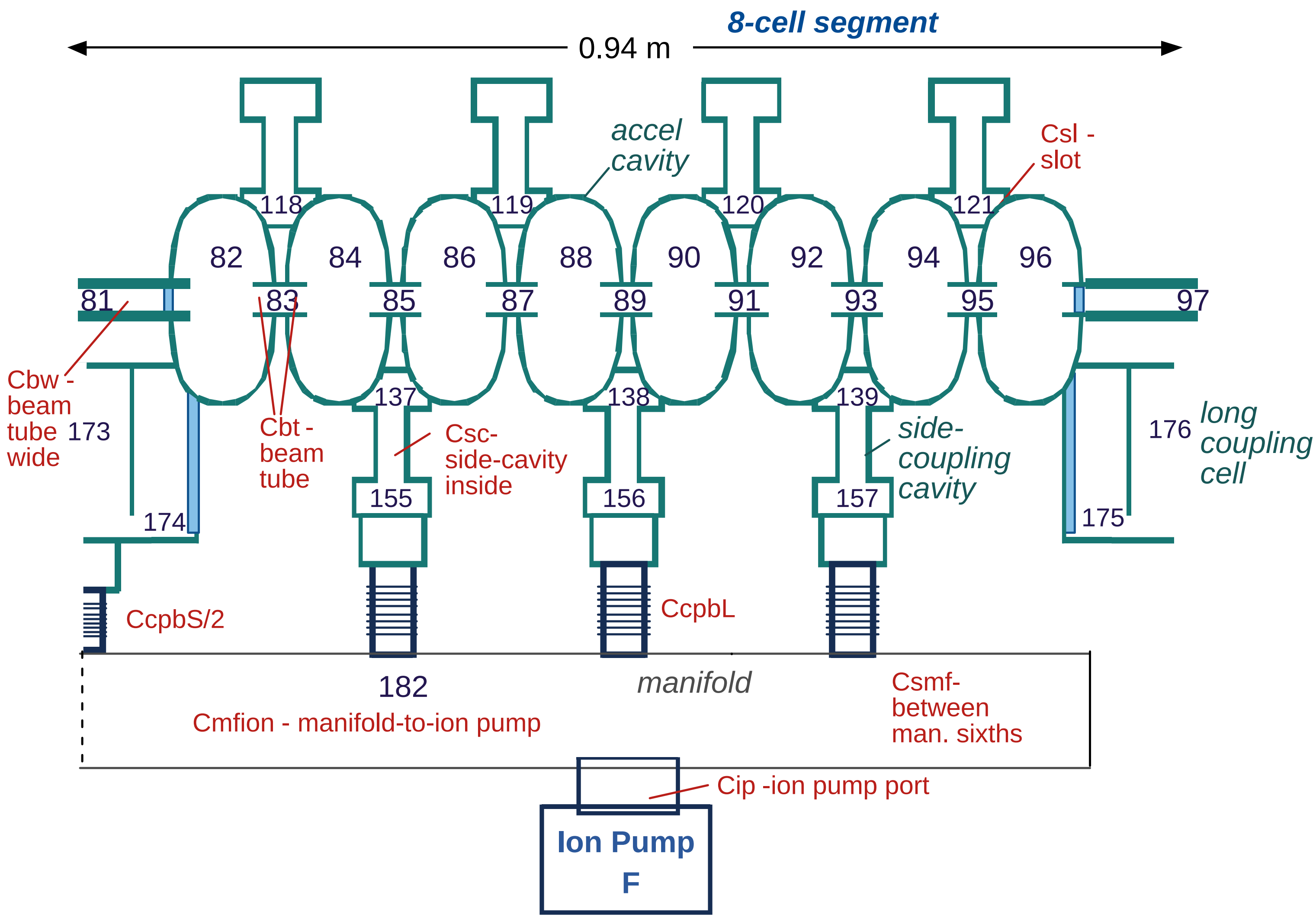


FIGURE 3.2.F. Layout of 6th of 6 segments of sub-volumes and conductances in the model of the SNS/CCL.

The gas load equations, shown below, are solved simultaneously for all sub-volumes for each time during pumpdown.

$V_i\, dp_i/dt = \Sigma\, Q_{i\,in} - \Sigma\, Q_{i\,out}$
where *i* is the index for the *ith* volume,
V is the volume (L);
dp_i/dt is the rate of change in pressure (Torr/sec);
$\Sigma\, Q_{i\,in}$ is the sum of outgassing or leakage into V_i (Torr-L/sec);
(surface outgassing is a function of time but permeability is constant)
and $\Sigma\, Q_{i\,out}$ is sum of the gas throughput from V_i into V_j,
where $Q_{i\,out} = C_{i\rightarrow j}\,(p_i - p_j)$
and $C_{i\rightarrow j}$ is the conductance (L/sec);
and/or $\Sigma\, Q_{i\,out}$ is sum of the gas throughput out of V_I,
where $Q_{i\,out} = S\, p_i$,
where S, the effective pump speed (L/sec), is
$S = S_p(p_i)\, C_p / (S_p(p_i) + C_p,$
where C_p is the conductance between V_i and the pump
and $S_p(p_i)$ is the pressure dependent pump speed.

3.1.2.1 Gas Loads

All vacuum-facing surfaces, except for the manifold, bellows, spool pieces and gate valves, are composed of OFE copper. The manifold, bellows, spool pieces and gate valves are electropolished stainless steel. The transient outgassing rate for these components is a combination of three distinct conditioning periods and is shown in Fig. 3.3. The early outgassing rate (first hour) is taken from Roth [3.2]. The history from 2 to 80 hours is taken from measurements made from the APT/LEDA Hot Model, a coupled-cavity drift tube linac structure [2.6]. As a conservative design measure, a limiting outgassing rate was chosen in the current study. Prior to rf conditioning the final outgassing rate for the copper is assumed to be 2.5 x 10^{-9} Torr-L/sec/cm^2. After conditioning the final rate for the copper is 8 x 10^{-11} Torr-L/sec/cm^2. The rate for the stainless steel is assumed to be 1 x 10^{-10} Torr-L/sec/cm^2 for both the pre- and post-conditioning phases. For modeling convenience, the final outgassing rate is assumed to occur at 100 hours. Note however, in Fig. 3.3, the LEDA Hot Model data shows that lower outgassing rates can be achieved beyond 100 hours of conditioning.

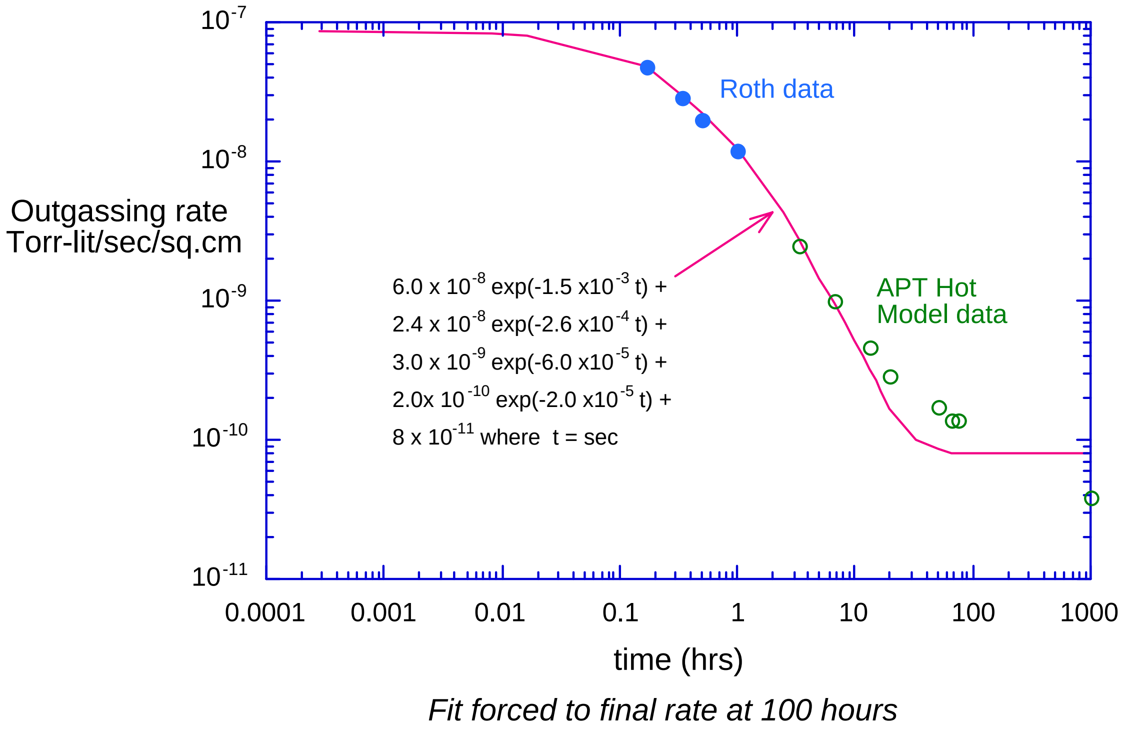


FIGURE 3.3. Pre- and Post-Conditioning Fits for Outgassing Rates for Copper. The stainless steel rate is assumed to be the same as the post-conditioning fit for copper.

The design of all seals and penetrations, and their calculated gas loads are listed in the Tables of Section 2.3 and Appendix H for all four CCL modules. As summarized in Table 3.5, in a typical module, the gas loads from seals represent only 5% of the total.

3.1.2.2 Pump Models

For each pump, the dependence of pump speed on local pressure $S_p(p_i)$ was scanned from the manufacturer's catalog and fit to a numerical formula. An example of this for the Captorr 300 conventional ion pump for dry air is shown in Fig. 3.4. To solve for other gases, a multiplier is used as shown in Table 3.4. These factors are taken from the vendor catalogs.

TABLE. 3.4. Pump scaling factors for various gases.

Gas (mass in amu)	Varian Turbo 300	PHI conv. Ion Pump
Air 28.98	1.00	1.00
H_2 2.016	0.75	2.20
H_20 18.016	1.00	1.00
N_2 28.02	1.00	0.85
$CO_{2\ 44.01}$	1.00	1.00

For the roughing pump, the gas load balance is solved with an initial pressure at atmospheric. All gases are treated the same through the roughing pump. The roughing time is chosen to be 27 minutes so that the final beamline pressure is 0.05 Torr. A Varian PTS 300 scroll pump with a working pump speed of 250 L/min was used in the numerical model. Next the final pressures for the 182 sub-volumes were saved to provide the initial conditions for the turbo pumping phase.

The turbo pump was on for 18 hours – the time needed to achieve 5 x 10^{-7} Torr in order to safely turn on the ion pumps. This final pressure was about 80% of what could be achieved if the turbo pump was on for 100 hours. This long pump-down time resulted because the outgassing rate is relatively high during the initial pump-down phase (<100 hrs).

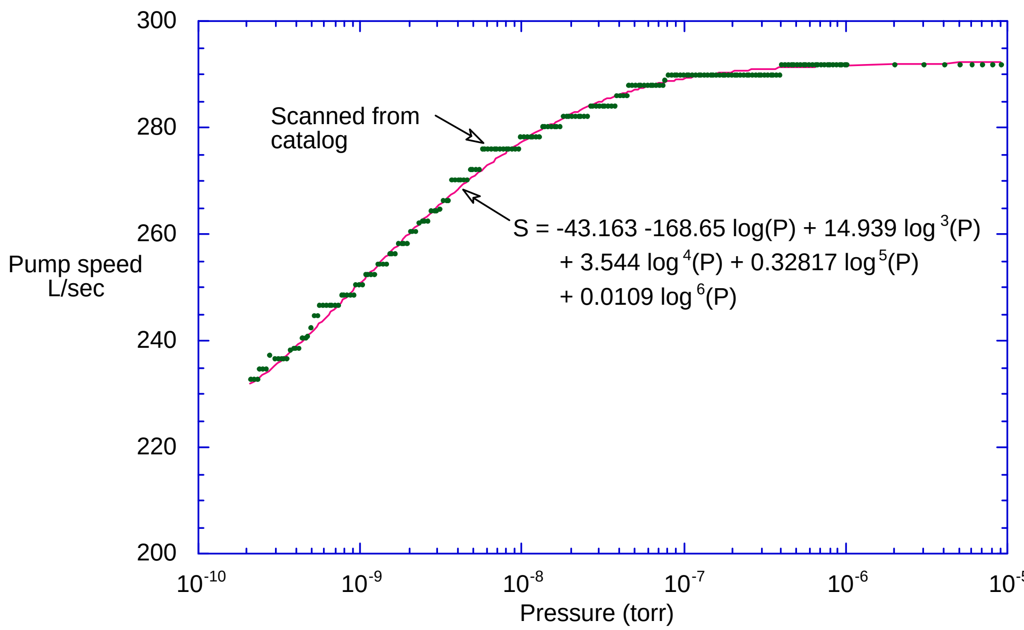


FIGURE 3.4. Dependence of pump speed on pressure for a PHI 300 Captorr conventional ion pump. The data was scanned from the vendor catalog and a numerical expression was fit to the data and used in the model.

3.1.2.3 Conductance Formulas

The majority of the conductances in the CCL vacuum model, correspond to that of molecular flow in a short tube or through an orifice. The molecular conductance of air in a short tube is given by Roth [3.2] as:

$$C_{shorttube,air} = 12.1(\frac{D^3}{L})K \text{ (Liters/second)}$$

where D is the inside diameter of the tube in cm, L is the tube length in cm, and K is Clausing factor given as:

$$K = \frac{15(L/D)+12(L/D)^2}{20+38(L/D)+12(L/D)^2}$$

The molecular conductance of air through an aperture of area A in cm^2 is given by roth [3.2] as:

$$C_{aperture,air} = 11.6A \text{ (Liters/second)}$$

When the various gasses were studied, all conductances were multiplied by the square root of the ratio of the molecular weight of air (28.98) to that of the particular gas species, as shown in Table 3.4.

The detailed areas, volumes conductances, and final outgassing rates are summarized in Table 3.5.

TABLE. 3.5. Volumes, areas, outgassing rates and conductances for each component in the CCL half-module numerical model. (Conductance values in molecular flow are listed).

Sub-volume component	Area (cm^2)	Volume (l)	Conduct-ance (l/s)
Beam tube	53	0.04	43 (HALF-LENGTH)
Wide beam tube	419	0.31	12 (HALF-LENGTH)
Accelerator cavity	1601	4.09	-
Slot	-	-	341
Side-coupling cavity (SCC)	739	0.84	227
Bridge coupler (BC) end (1/3)	2195	6.44	-
Bridge coupler center	3860	15.8	
Slot btw.BC ends and center	-	-	147
Short bellows (under BC)	308	0.37	
Long bellows (under SCC)	605	0.87	
Coupling port	130	0.13	68
Port (includes 6” gate valve) for turbo 300	973	3.59	585
Port for ion pump	353	1.30	1303
Sixth of 6” manifold	4498	17.1	352
Cturbo (port, vlv. and manifold sixth)	-	-	220
Cion (port and manifold sixth)	-	-	369
Manifold end	182	-	-
Total copper area = 159,918cm^2			
Total stainless steel area = 40,457 cm^2			
Total volume = 531 L			
Total outgassing final gas load = 1.8 x 10^{-5} Torr-L/sec			
Total seal leak+outgassing rate = 8.7 x 10^{-7} Torr-L/sec (5% of total)			

3.1.3 Results

3.1.3.1 Summary

The numerical model was run with a range of pump sizes and with different manifold diameters to determine the optimal configuration hardware. A 6” ID manifold was selected because it provided a large enough conductance yet was small enough to allow ease of installation. For comparison, a simulation was performed using an 8” ID manifold. The results indicated that the average beamline pressure dropped by only 7% from 4.4 to 4.1 x 10^{-8} Torr with the use of the larger manifold. The benefit of a larger manifold conductance (8” vs. 6”) was offset by the increased outgassing rate of the manifold’s steel surface and was also negated by the limiting conductance of the bellows. Further calculations of the manifold comparison are contained in Appendix J.

Consideration was made for assuming the requirements for conditioned surfaces while achieving a base pressure that was 1/2 of the required value (8.9×10^{-8} Torr) for safe operation. This effective safety factor of 2 accounts for the possibility of pump failure, unknown leaks or localized high outgassing rates that are not accounted for in the numerical model. In addition, the number and size of pumps were chosen to minimize costs. As seen in Fig. 3.1, for one-half of CCL Mod. 1 (5.6 meter length for 6-segments), the configuration chosen was one turbo cart consisting of one turbo pump-down cart, consisting of a Varian 300 PTS scroll pump and a Varian Turbo 300, and five Physical Electronics 300 Captorr conventional ion pumps to maintain the steady-state base pressure. The detailed areas, volumes, conductances, and final outgassing rates are summarized in Table 3.5. The conductances are also labeled in Figure 3.2. The pressure history for pumping the post-conditioned surfaces in shown in Fig. 3.5.

3.1.3.2 Turbo Pump Optimization

The turbo pump has been optimized based on its functions to achieve a pressure of 5 x 10^{-7} Torr so that the ion pumps can be safely turned on during normal operation. After 18 hours of pumping, one turbo 300 achieves this pressure in the vacuum manifold for half of a CCL module (see Fig. 3.5). As shown previously, the series conductance, $C_{turbo,}$ of the turbo pump port, gate valve, and manifold sixth-length is 220 L/sec. The optimized model does not include the use of an extension piece to connect the turbo pump cart to the turbo gate valve. Generally the extension should be designed to be of minimal length and maximum diameter so that its conductance is much larger than the 220 L/sec discussed above. To study this, a 6”elbow was added to the turbo pump port gate valve with an axis length of 9.5 inches in both directions. This elbow has a molecular conductance of 461 L/s (using the elbow formula in Roth [3.2]). This reduces C_{turbo} to 149 L/s. This reduced conductance has the effect of requiring an additional 2 hours to achieve the same manifold pressure or if pumping is stopped at 18 hours then the manifold pressure is 5.3 x 10^{-7} Torr (20% higher). Thus the effect of the extension conductance will be to increase the pumpdown time for that module.

3.1.3.3 Ion Pump Optimization

The main function of the ion pumps is to achieve a beamline base pressure significantly below 10^{-6} Torr during conditioning (turbo pump on) and reach 4.4 x 10^{-8} Torr after conditioning. This base pressure limit corresponds to a beam energy of 186 MeV, and hence is conservative for all four CCL modules. As will be shown later, assuming a mixture of gases results in a lower pressure than just modeling air with a composite molecular weight of 28.98 amu. Hence for simplicity of modeling and with added conservatism, the pump configurations are optimized assuming one gas of pure "air".

With the standard outgassing rate of 10^{-10} Torr-L/sec/cm^2 after 100 hours of pumping air, it was found that 6 ion pumps, installed on a half-module, provided an average beamline pressure of 4.84x10^{-8} Torr, which is slightly above the design goal of 4.4x10^{-8} Torr. If 5 ion pumps are used and the surface outgassing rate is reduced to 8x10^{-11} Torr-L/sec/cm^2, then a base pressure of 4.03x10^{-8} Torr can be obtained. This outgassing rate can be achieved with either slightly more aggressive cleaning than the rate of 10^{-10} Torr-L/sec/cm^2 requires or by extending the vacuum conditioning time by approximately 20 hours. The rate of 8 x 10^{-11} Torr-L/sec/cm^2 was observed at that 120 hours in the results for the APT/LEDA CCDTL Hot Model experiment as shown previously in Fig. 3.3. Again this is a trade-off of costs up front that must be compared to labor costs of waiting 20% longer whenever the system is pumped down.

Figure 3.6 shows beamline pressure versus the number of Captorr 300 ion pumps for half of a CCL module. Note that if one ion pump fails, the pressure requirements are still met.

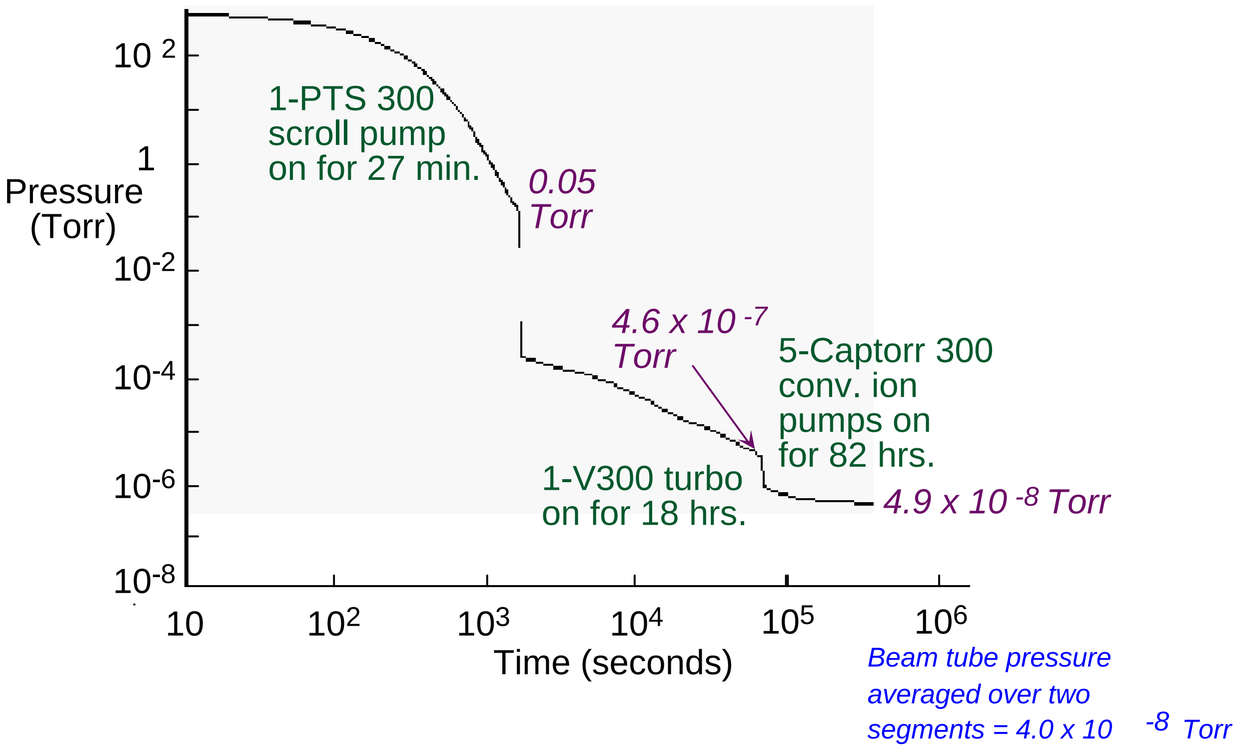


Figure 3.5. History of peak beamline pressure (sub-volume 1) from atmosphere to the base pressure for CCL Mod. 1. Pump configuration is for one manifold which services half of a typical CCL module. The final copper outgassing rate is 8×10^{-11} Torr-L/sec and the final stainless steel outgassing rate is 1×10^{-10} Torr-L/sec.

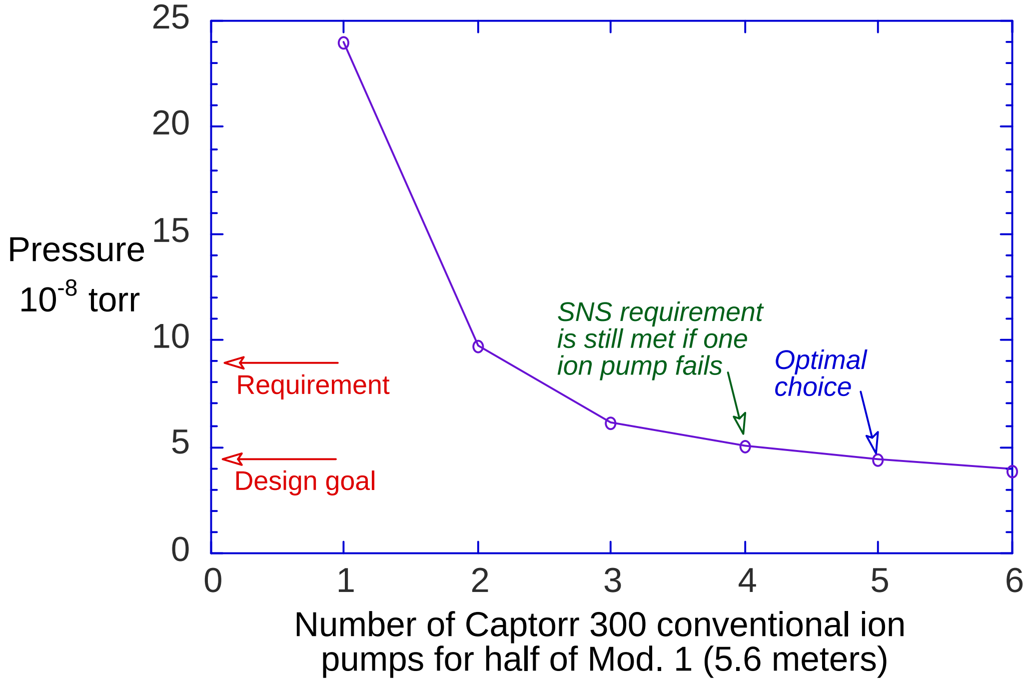


FIGURE. 3.6. Average beamline pressure versus number of Captorr 300 ion pumps for half of a CCL module. The final copper outgassing rate is 8 x 10^{-11} Torr-L/sec and the final stainless steel outgassing rate is 1 x 10^{-10} Torr-L/sec.

3.1.3.4 Bellows – The Limiting Conductance

Recall that this vacuum analysis was conducted using a 6" ID, 5.6-m long manifold that was connected to the side coupling cell and bridge coupler ports with flexible formed bellows. For a half-module, there are 18 long bellows attached to the coupling ports on the bottom side coupling cells and 5.5 short bellows attached to the bridge couplers. As shown in Fig. 3.2.A, the bellows/port path is the most limiting conductance in the CCL vacuum system (at 47 L/sec for the side coupling cell connection and 39 L/s for the bridge coupler connection). These conductances are sufficient for the five ion pumps to meet the vacuum requirements for the half-module provided that the copper surfaces outgas at 8 x 10^{-11} Torr-L/sec/cm^2 and the stainless steel surfaces outgas at 1 x 10^{-10} Torr-L/sec/cm^2.

3.1.3.5 Gauge Calibration

In the numerical model, pressure values were determined at each sub-volume. For the reference case of 5 ion pumps and an outgassing rate of 1 x 10^{-10} Torr-L/sec/cm^2, the lowest final manifold pressure (in sub-volume 182) of 2.21 x 10^{-8} Torr achieved. Consequently, a pressure gauge at this location would read a value sufficiently lower than the *average* beamline pressure (at 4.83 x 10^{-8} Torr). Just for reference, the *maximum* beamline pressure (in sub-volume 1) is 5.6 x 10^{-8} Torr.

According to the current CCL vacuum system design, the CCL beamline high vacuum pressure measurements will be made with cold cathode gauges mounted to a spool piece on the vacuum manifold. These pressure readings will be significantly lower than the beamline pressures, as shown in Figure 3.7. The modeling results indicate that the calibration factor for reading the average beamline pressure by a gauge mounted on the vacuum manifold spool piece, should be:

$$\frac{average\, beamline\ pressure}{manofold\ pressure} = \frac{4.83x10^{-8}}{2.65x10^{-8}} = 1.82$$

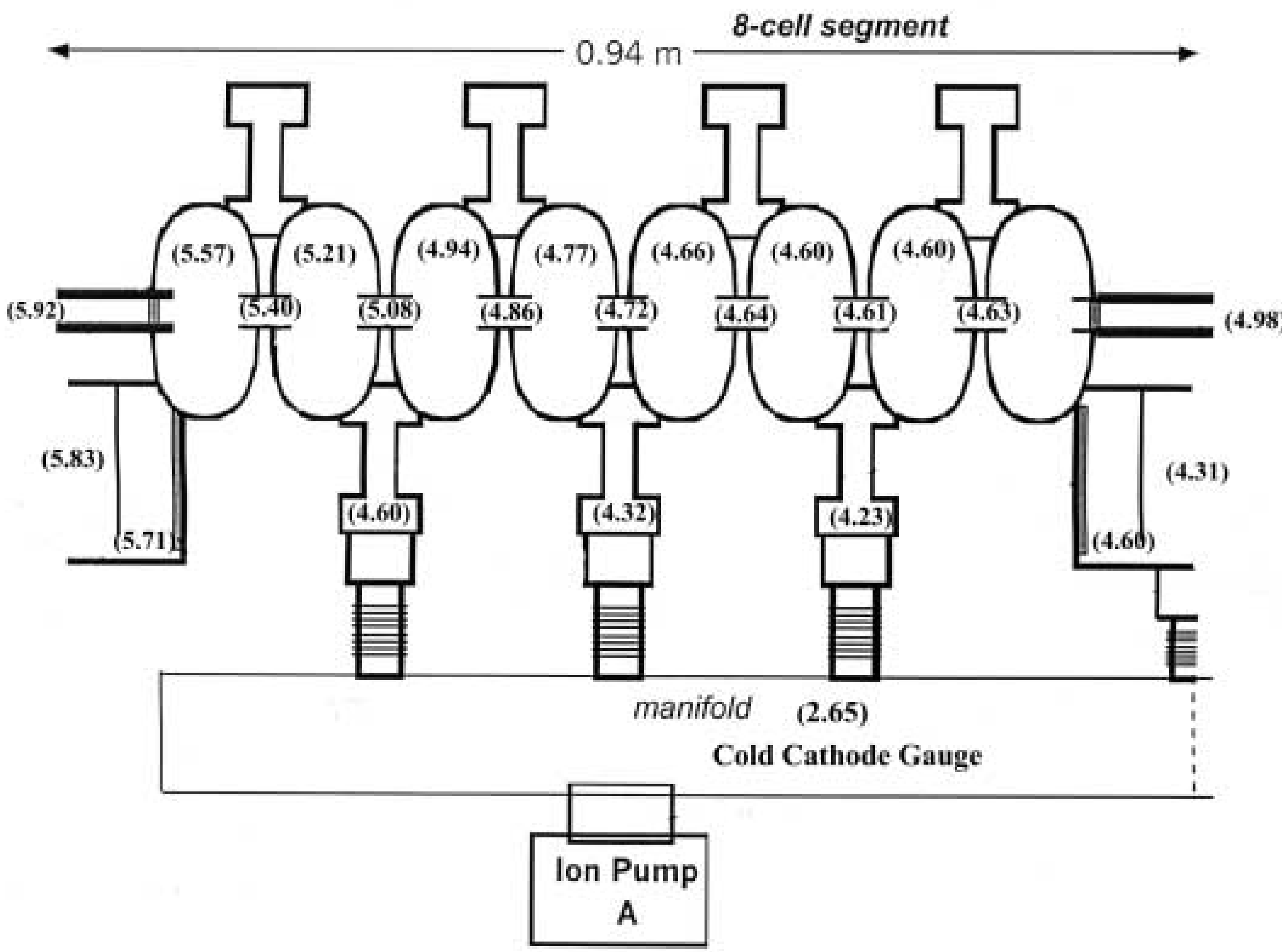


Figure 3.7. Pressure distribution in the first segment of CCL module 1 (multiply all values by 10^{-8} Torr).

3.1.3.6 Model Results with Multiple Gas Species

The previous vacuum analyses were conducted with a gas species of "air", which was assumed to have a composite molecular weight of 28.98 amu. However according to the scattering study of Shafer [1.6], the scattering of the proton beam is highly dependent on the gas species present in the vacuum environment. Consequently, the vacuum analysis needed to consider the effects of multiple gas species on the pumping speed and obtainable base pressures.

In performing the multiple gas species vacuum study, one cannot assume that the gas load is formed from a typical composite of atmospheric air. The gas composition depends on what is absorbed and then desorbed from the metal surfaces and what is most likely to leak or permeate in through seals. The most relevant and recent vacuum gas composition data published for a copper accelerator structure was that obtained from the APT/LEDA CCDTL hot model, following vacuum and RF conditioning [2.6]. The RGA data for the APT/LEDA CCDTL is quite similar to that obtained from module 6 of the LANSCE CCL (see Appendix B). Table 3.6 summarizes the gas composition measured in the APT/LEDA study and applied to the CCL vacuum model.

Also shown in Table 3.6 are the proton scattering weighting factors that were describe in Section 1.4 to be used in determining the total effective pressures. A measure of the contribution of each gas species to the scattering of the proton beam is obtained by multiplying the scattering weighting factor by the gas composition percentage, as shown in the last column of Table 3.6 for the gas species distribution obtained for the APT/LEDA CCDTL hot model. As the last column of Table 3.6 indicates, based on the gas composition and weighting factors, the nitrogen gas will have the greatest contribution in determining the total maximum pressure, while hydrogen, water, and carbon dioxide will have a lesser impact for this particular study. Consequently, the previous study in which the vacuum gas was considered to be 100% air, will give more conservative results in determining pumping speeds and base pressures, than study with multiple gas species. Never the less, the amount of conservatism should still be determined by performing the multiple gas species study.

TABLE 3.6. Measured gas mixes in APT/LEDA hot model, assumed gas mix for numerical model, proton scattering weighting factors.

Gas	AMU	APT/LEDA Hot Model Gas Species Data % Of Composition %]	Assumed CCL Model Gas Composition, C [%]	Proton Scattering Weighting Factor, W (See Section 1.4)	W×C/100
H_2	2.02	18	20	0.15	0.03
CH_4	16.03	3	-	-	-
H_2O	18.02	20	20	0.66	0.13
N_2	28.02	49	50	1.0	0.50
CO_2	44.01	7	10	1.5	0.15

In the multiple gas species analysis, the vacuum model was repeatedly run for each individual gas species of interest, including H_2, H_2O, CO_2, and N_2, with the corresponding conductance values and pumping characteristics included for each particular gas species. In each of the model runs, the total gas load described in Section 3.1.2.1 was applied to obtain the average beamline pressure P_{avg}, assuming that the entire gas load was made up of the single gas species. To correct for the fact that only a portion of the total gas load is made up of a particular gas species, the average drift tube pressure obtained for each gas species, was multiplied by the composition percentage, C/100, to obtain the partial pressure of each gas species, or

$$P_{gas} = P_{avg} \times C/100,$$

where P_{avg} and P_{gas} are listed in Table 3.7 for each gas species. Finally, the weighted partial pressure for each gas species, $P_{gas,w}$, was calculated:

$$P_{gas,w} = P_{avg} \times C/100 \times W = P_{gas} \times W,$$

which are listed in the last column in Table 3.7.

The total effective gas pressure from the multiple gas species was then obtain from

$$P_{total} = P_{H2,w} + P_{H20,w} + P_{N2,w} + P_{CO2,w}, = 6.76 \times 10^{-8} \text{ Torr},$$

which is well below the maximum allowable pressure of 8.9×10^{-8} Torr and the design goal of $4.4{\times}10^{-8}$ Torr. Also note that the weighted multiple gas species average pressure value of 3.61×10^{-8} Torr is 19% below that of 4.44×10^{-8} Torr calculated using air.

TABLE. 3.7. CCL model results for each gas and their partial and weighted partial pressures.

Gas (amu)	**Average Beamline Pressure P (10^{-8} Torr) with 100% Gas** P_{avg}	**Average Partial Pressures (10^{-8} Torr)** $P_{gas} = P_{avg} \times C/100$	**Weighted Partial Pressures (10^{-8} Torr)** $P_{gas,w} = P_{avg} \times C/100 \times W = P_{gas} \times W$
H_2 (2.016)	1.43	0.29	0.04
H_20 (18.016)	3.76	0.75	0.50
N_2 (28.02)	**4.60**	2.30	2.30
CO_2 (44.01)	5.15	0.52	0.77
air (28.98)	**4.43**		
TOTAL Composite		**3.86**	**3.61**

3.1.4 Conclusions

It was demonstrated that the vacuum pump configuration of using five 300 L/s ion pumps and one 300 L/s turbo pump backed by 250 L/m scroll pump is an optimized design for vacuum conditioning and operating a vacuum system for half of a CCL module. The design not only satisfies the requirements but also provides comfortable operation margins. The key conclusions are summarized in Table 3.8.

It should be noted that the average beamline pressure depends heavily on the outgassing rate assumed in the numerical model. In general this pressure is linearly dependent on the surface-outgassing rate. Thus, cleanliness during manufacturing and assembly is essential to achieving the predicted base pressure.

TABLE. 3.8. Key conclusions from CCL RF structure vacuum modeling.

Design Function	FDR Modeling Results
Vacuum Level – Air	Sufficiently provided for average beamline pressure of 4.44×10^{-8} Torr. Safety margins of 2 for base pressure.
Vacuum Level – Multiple Gas Species	Satisfactory results for mixed gases with H_2, H_2O, N_2 and CO_2.
Gas Load % Distribution	Surface outgassing = 90% Seal leaks = 5% Diagnostic outgassing = 5%
Main CCL Module Vacuum Pump Selection	Ten 300 L/s ion pumps, two 300 L/s turbo pumps, two 250 L/m scroll pump.
Roughing Function	Less than 1/2 hour
Turbo Conditioning	18 Hours
Ion Pump Operation	Reaching 4.4×10^{-8} Torr in 82 Hours
Gauging Calibration	Cold Cathode gauge at the vacuum manifold spool reads approximately 50% lower than the average beamline pressure.

3.2 RF Window Vacuum Model

3.2.1 Numerical Model Description

To correctly size the NEG pumping cartridges, the RF window and waveguide outgassing loads, desired operating base pressure, pump port dimensions, and the RF shielding port geometry must be known. The effective pump speed, S_{eff}, required to overcome the gas load is given by [2.6]

$$S_{eff} = (Q_w \times A_w + Q_{wg} \times A_{wg})/P_{base}, \qquad (3.2.1)$$

where Q_w = RF window outgassing rate (Torr L/s/cm^2)
A_w = RF window vacuum surface area (330 cm^2)
Q_{wg} = waveguide outgassing rate (10^{-10} Torr L/s/cm^2)
A_{wg} = waveguide surface area (2787 cm^2)
P_{base} = base pressure in waveguide transition section (10^{-7} Torr).

A typical gas load for the stainless steel waveguide surface, Q_{wg}, is 10^{-10} Torr L/s/cm^2 [3.2]. The gas load for the RF window varies during RF conditioning. Cummings [3.4] found that for RF windows similar to those designed for the SNS Linac, a steady-state outgassing rate of approximately 5×10^{-9} Torr L/s/cm^2 was achievable for RF feed-through powers of 600 to 1000 W after several days of vacuum and RF conditioning. Cummings indicated that outgassing rates of at least an order of magnitude greater (5×10^{-8} Torr L/s/cm^2) were observed during early RF conditioning [2.4].

If it is assumed that all of the vacuum pumping is done through the RF shield (neglect the pumping through the iris by the main CCL vacuum pumping system), then the required NEG pumping speed, S_{NEG}, is higher than the effective pump speed and is given by [3.2]

$$S_{NEG} = S_{eff} \times [C_{port}/(C_{port} - S_{eff})], \qquad (3.2.2)$$

where C_{port} is the conductance of the RF shield, C_{rfs}, the pump attachment nipple, C_{nip1}, and the NEG housing nipple, C_{nip2}, or

$$C_{port} = (C_{rfs}^{-1} + C_{nip1}^{-1} + C_{nip2}^{-1})^{-1} \qquad (3.2.3)$$

From a vacuum pumping perspective, it is advantageous to maximize the diameter of the pump port and maximize the conductance of the RF shielding. The current waveguide transition section will allow a nipple with an inside diameter of 4.87 in. The RF shield design, shown in Figure 3.8, consists of 60 rectangular slots with a width of 0.125 in. (0.318 cm), a depth of 0.25 in. (0.635 cm), and various lengths. These shield slots plus the nipple provide an attenuation factor of 71 dB to the RF energy, which results in a RF leakage power to the NEG pump of less than 1 W (see Appendix I). The conductance for a rectangular aperture, C_{slot} (Liters/s), with an air medium is given by [3.2]

$$C_{slot} = 30.9\, a^2 b^2 K/(a+b)/L, \qquad (3.2.4)$$

where a is the slot length (cm), b is the slot width (cm) (a>b), L is the slot depth (cm) or shield thickness, and K is a geometrical correction factor which is approximately 1.4 for the chosen slot geometry (see Appendix I). The conductance of the RF shield, is then the summation of the individual slot conductances

$$C_{rfs} = \sum_{i=1}^{60} C_{slot,i} \qquad (3.2.5)$$

3.2.2 Results

Using an RF window outgassing rate of 5×10^{-8} Torr L/s/cm^2, a waveguide outgassing rate of 10^{-10} Torr L/s/cm^2, and a base pressure of 10^{-7} Torr, Equation (3.2.1) predicts an effective pumping of 168 L/s is required to overcome the gas loads. For the slot geometries given in Figure 3.8, the RF shield conductance is 630 L/s. From Appendix I, the two nipple conductances, C_{nip1} and C_{nip2}, are 602 L/s and 1092 L/s, respectively. Consequently, the total conductance between the NEG pump cartridges and vacuum environment inside the waveguide is 240 L/s. Using this conductance and an effective pump speed of 168 L/s in Equation (3.2.2), the required NEG pump speed is 560 L/s.

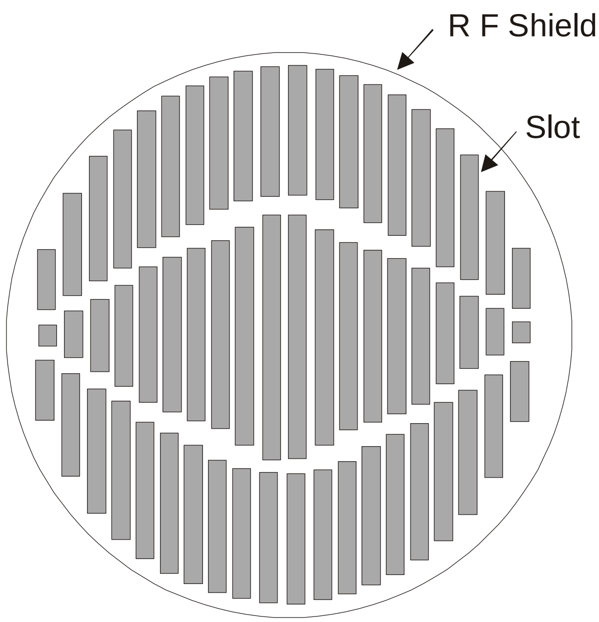


Figure 3.8. RF grill design for the NEG pump on the CCL RF window.

3.2.3 Conclusions

The RF window vacuum system will be configured around a high capacity NEG pump. Engineering calculations show that during early conditioning of the RF window can be overcome with a NEG possessing a pumping speed of at least 560 L/s. This assumes that the initial outgassing rate of 5×10^{-8} Torr L/s/cm^2 for the RF window is correct. According to Cummings [2.4], this outgassing rate is very uncertain. Consequently, it is recommended that a conservative NEG pumping speed on the order of 1000 L/s be incorporated in the design. A 1300 L/s NEG pump by SAES is being recommended for the RF window pumping, as this pump is a convenient off-the-shelf component and has seen successful operation on the APT/LEDA RFQ RF window vacuum pumping systems.

Also note that in the final RF window vacuum system design, a slotted RF shield will be placed across the NEG pump port to minimize the leakage of RF power from the waveguide. The NEG pump will be supported by a 70 L/s turbo pump, which in turn will be backed by a dry roughing pump from the main CCL vacuum pumping system. The turbo pump will be used to pump inert gases and for conditioning the NEG pump. Finally, a cold cathode gauge will be employed to monitor the vacuum pressure in the vicinity of the RF window. This vacuum hardware configuration is similar to that be used on the LEDA RFQ RF window vacuum system, which has experienced successful operation

3.3 Beam Diagnostics Vacuum Model

In order not to cause beam loss from H minus stripping in the vacuum environment, the vacuum pressure has to be closely controlled to the levels specified earlier in this report. Of concern here is the possible stripping that could occur in the CCL inter-segment regions caused by excessive outgassing of beam diagnostics. The beam diagnostics reside in close proximity to the beam line and are located in the intersegment regions of the CCL which have low vacuum conductance. Consequently, the gas loads from these diagnostic instruments, the available pumping speeds, and resulting beamline base pressures must be carefully analyzed.

For reference, a layout drawing showing the types and locations of all beam diagnostics along the DTL and CCL, is provided in Appendix C.

3.3.1 Numerical Model Description

The vacuum pressure model that is proposed in this calculation, and shown in Figure 3.9, is based on several simplifying assumptions. First, it is assumed that a beam diagnostic device resides in consecutive intersegment spaces along a representative portion of the CCL. Next, a saw-toothed shaped pressure profile is assumed to exist along the length of the CCL beamline, with the minimum pressure residing in the center of a segment and the maximum pressure residing in the intersegment beam tube where the diagnostic device resides. It is further assumed that the lowest vacuum pressure level, in the middle of the CCL segment, is at the design pressure of $4.44E^{-8}$ torr, as obtained in the CCL module vacuum analysis of Section 3.1 (see Figure 3.7). The mid-point pressure along this profile, is set to $8.87E^{-8}$ torr, which this is the maximum average beam tube pressure in the CCL at which unacceptable beam stripping begins to occur. It must be emphasized that local pressures along the beamline can be above $8.9E^{-8}$ Torr, so long as the average pressure over a length of 5 meters is below $8.9E^{-8}$ Torr. Since the pressure curve is linear, it is easy to determine the pressure in the center of the inter-segment region. The region that was selected for analysis was the last inter-segment region in the CCL at the end of Module #4. This is a worst case analysis because it has the longest inter-segment region and the highest vacuum requirement.

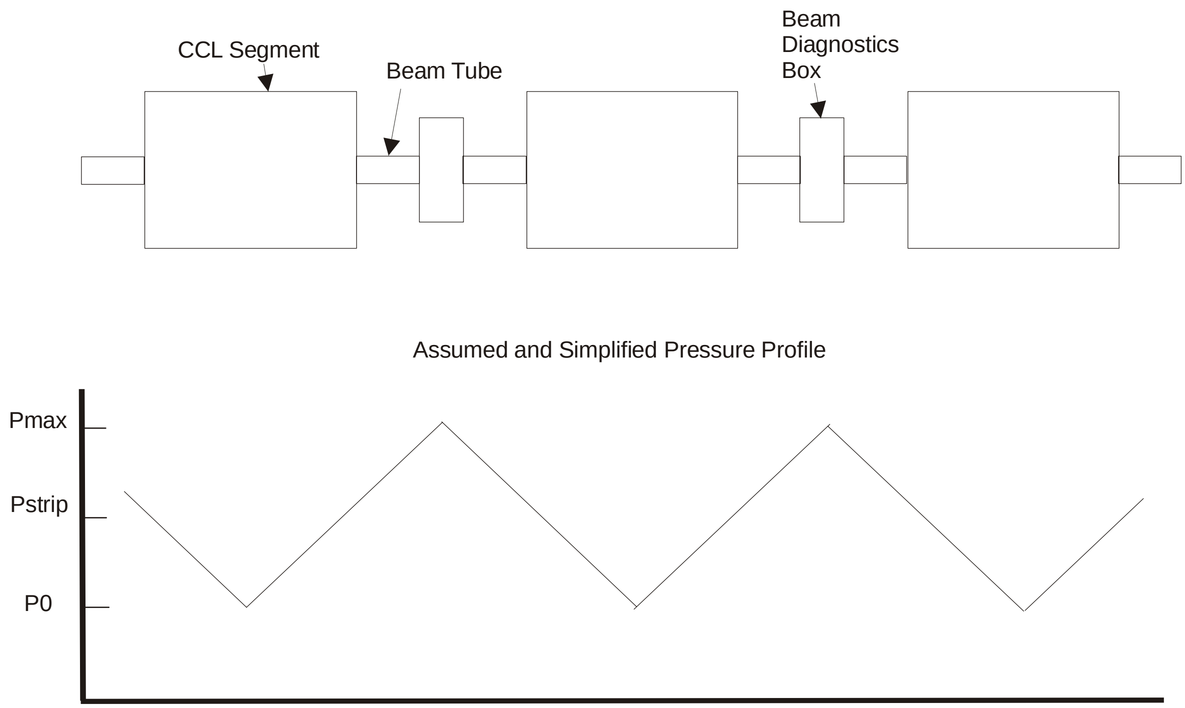


Figure 3.9. CCL beam diagnostic vacuum model.

3.3.2 Results

The basic calculations for the model are displayed here. See Appendix I for more details.

P0 is assigned to the operating pressure ($4.44E^{-8}$ torr) in the center of the segment and P_{max}, is the pressure in the middle of the inter-segment region. Therefore:

$$P_{strip} := \frac{1}{2}(Pmax + P0)$$

$$Pmax := 2 \cdot P_{strip} - P0$$

$$Pmax = 1.33 \times 10^{-7} \quad \text{torr}$$

The total outgas load from the inter-segment region and into the two CCL segments can be represented as:

$$Qtotal := 2 \cdot C_{mT} \cdot \left[Pmax - \left(\frac{2}{3} Pmax + \frac{1}{3} P0 \right) \right]$$

$$Qtotal = 9.792 \times 10^{-7} \frac{(torr \cdot liters)}{sec}$$

where C_{mT} is the conductance of half of the beam tube.

Subtracting the beam tube surface gas load from this total gas load (see Appendix I for more details), gives the maximum allowable beam diagnostic outgas rate for the CCL intersegment region as:

$$\text{Q\_max\_diagnostic} = 7.35E^{-7} \text{ (torr*liters)/sec}$$

3.3.3 Conclusions

In order to give as much tolerance as possible to designing the diagnostic equipment, a model was adopted that would allow pressure spikes along the CCL beam line that exceeds the "stripping" pressure. Shafer [2.6], who did the stripping calculations, feels that it is allowable to exceed the stripping pressure for short distances ie, 5 meters. This calculation was very conservative because at lower beam energies the vacuum requirement isn't as high and the inter-segment regions are shorter, and the pressures within the segments are slightly lower than the profile used in the present model.

The key conclusion to this model is that the maximum allowable outgassing rate for the beam diagnostic hardware in the intersegment region of the CCL, can not exceed $7.35E^{-7}$ (torr*liters)/sec.

4.0 Mechanical Design and Analyses

4.1 Introduction

This section of the report discusses many facets associated with the mechanical design of the CCL vacuum system. These topics include a discussion on the types of vacuum materials that may be used in the radiation environment, the design of the turbomolecular pump cart, the design aspects of the vacuum manifold including alignment and stress, and mounting of the ion pumps.

4.2 Materials

The radiation emanating from a particle accelerator can degrade mechanical properties of materials in close proximity to the beam line. The extent of this degradation will depend on the dose rate and cumulative radiation dose, as well as other factors such as operating temperature, mechanical stress, and exposure to air [4.1]. Scientists and Engineers at CERN have compiled a fairly extensive data base which relates radiation damage to cumulative dose rate for a variety of materials [4.2]. Table 4.1 lists the radiation damage (cumulative radiation dose) limits for various materials used around high-energy particle accelerators [4.2].

Table 4.1. Radiation damage limits for materials used around high-energy particle accelerators [4.2].

Material	Cumulative Dose Limit (Rad)
Polyvinyl Chloride (PVC)	1×10^{8}
Polyurethane Rubber (PUR)	7×10^{7}
Ethylene-Propylene Rubber (EPR)	8×10^{7}
Styrene-Butadiene Rubber (SBR)	4×10^{7}
Polychloroprene Rubber (Neoprene)	2×10^{7}
Chlorosulfonated Polyethylene (Hypalon)	2×10^{7}
Acrylonitrile Rubber (Buna-N)	2×10^{7}
Acrylic Rubber	8×10^{6}
Silicone Rubber (SIR)	9×10^{6}
Fluoro Rubber	9×10^{6}
Butyl Rubber	2×10^{6}
Tefflon (PTFE)	1×10^{5}
Fluorocarbon (Viton)	1×10^{7}
Nylon	1×10^{7}
Plexiglass	1×10^{7}
Phenolic Resin	1×10^{6}
Metals	1×10^{10}

Assuming a particle beam loss of 1 Watt/meter along the entire SNS linac, the prompt radiation dose rate, in close proximity to the accelerator, will be approximately 10 Rad/hour at the low energy (80 MeV) end of the CCL and roughly 20 rad/hour at the high energy (185 MeV) end [4.3]. If the SNS accelerator were to run for 300 days/year [4.4], the maximum cumulative dose for a year would be approximately 1.44×10^5 Rads. This assumes that the radiation dose rate when the beam is shut off, is significantly less than 10 Rad/hour.

To determine which materials will be acceptable for the DTL and CCL vacuum systems (from a radiation performance perspective), the material cumulative dose limits need to be compared to the annual dose present during accelerator operation. Assuming a thirty year desired lifetime for all materials in the Linac vacuum system, the total cumulative dose would be 4.3×10^6 Rads. Thus the minimum acceptable dose rate limit for vacuum system materials near the linac beam line must be greater than 4.3×10^6 Rads. Referring to Table 4.1, both Buna-N and Neoprene rubbers, and metals such as copper and stainless steel, would be acceptable from a radiation damage resistance perspective. These materials have been used on the LANSCE 800 MeV particle accelerator at Los Alamos National Laboratory with good success. Flexible Buna-N water lines on the LANSCE DTL have been observed to harden over time by a combination of radiation and atmospheric damage, however they have maintained working lifetimes of well over ten years [4.5]. In addition, Buna-N/Neoprene hoses have been used as flexible jumper water lines for the majority of the focusing and steering magnets on the LANSCE accelerator for the last twenty years [4.5]. Note that the annual cumulative dose rate estimated above was based on the high-energy end of the SNS linac and is thus very conservative for the majority of the room temperature linac structure.

4.3 Turbo Pump Cart

As discussed previously in Section 2.5, a portable turbo/scroll pump cart was selected for pumping the CCL module from atmospheric pressure, down to a low enough pressure ($>10^{-5}$ Torr) that the main ion pumps can be turned on. The portable turbo/scroll pump cart is a temporary pumping system to be used during the early vacuum and RF conditioning of the CCL module. The high pumping speed and flow through design makes the turbo pump ideal for conditioning the SNS linac. Upon completion of the conditioning stages, the turbo/scroll pump cart will be removed and be made available for other vacuum system operations. A pneumatic isolation valve will be placed on the CCL vacuum manifold pump port to allow for attaching and removing the turbo pump cart without impacting the vacuum environment.

The central feature of the CCL turbo pump cart is an oil-free 300 L/s turbomolecular pump, backed by an oil-free 250 L/min scroll pump. The turbo pump will be equipped with an inlet screen and a fan-driven air cooling system. The turbo pump will have an 8” Conflat flange for attaching to the CCL vacuum manifold pump port gate valve. The turbo pump will be attached to a translation platform that allows the pump to be elevated and rotated. In all, the turbo pump will have 3 translational (2 by movement of the cart) and 1 rotational degrees of freedom. The scroll pump will be mounted to the bottom of the cart with vibration isolators. The scroll pump will be connected to the turbo pump by a flexible, hydroformed bellows with KSO flanges. Each turbo pump cart will be equipped with a convectron gauge to monitor the foreline pressure between the turbo and scroll pumps, and an integrated controller that will monitor/control all system operations. This integrated controller will also be required to interface with the local CCL vacuum system PLC for remote operation. The vacuum pumps and controller will be mounted on a portable cart, as shown in Figure 4.1. The cart displayed in Figure 4.1, is a modified version of a standard cart provided by Varian. The additional translation devices were added to the standard cart configuration to allow the turbo pump to clear the CCL support structure and have enough translation to mate up with the spool piece gate valve. In addition, the cart was configured to be compatible with the DTL vacuum system and support structure.

A complete specification document that describes the necessary operational, mechanical, dimensional, and electrical features of the DTL/CCL turbo pump cart is contained in Appendix E. The required DTL/CCL turbo cart features should be compared against those required for other SNS vacuum systems (i.e., SCL, storage ring, etc.) so that its design can be adjusted to minimize the number of different cart designs needed for the SNS vacuum systems.

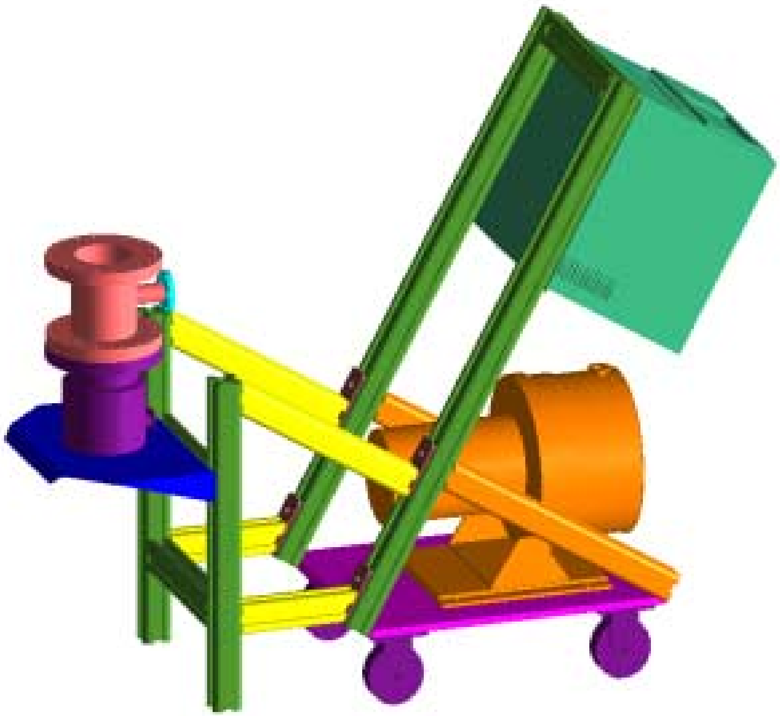


Figure 4.1. DTL/CCL turbo vacuum cart (see Appendix E for more details).

4.4 CCL Vacuum Manifold

This section describes the mechanical design of the CCL vacuum manifold. The design features of the manifold including its port geometries, material selection, manufacturing plan, alignment and mounting methods, etc. are described. In addition, stress analyses are presented for the manifold under different loading conditions.

4.4.1 Design

The CCL manifolds provide a large path for conductance of gases from the RF structures to the vacuum pumps and instruments. The manifold design was chosen to get a uniform pumping distribution along the length of the CCL with a minimal number of large-capacity vacuum pumps. The manifolds are made of six-inch outside diameter stainless steel tubes with a wall thickness of 0.125 inches. This size manifold has been shown by the vacuum analyses of Section 3, to provide adequate conductance with a reasonable out-gassing rate.

The length of the longest CCL module is approximately 15 meters (50 feet). A 15-meter structure is too cumbersome to fabricate, transport, and install the Linac tunnel at one time; hence, each module is being assembled from two half-module sections. To be consistent with the CCL configuration, each vacuum manifold will extend the length of one half a CCL module. In order to improve assembly and maintenance, the two manifolds making up one CCL module vacuum system, will not be directly connected together. Consequently, each CCL module will have two stainless steel manifolds, each running the length of a half of a module, and each capped off on either end with blank flanges.

Based on the current vacuum system design, each manifold will be connected to five ion pumps to maintain the required base pressure. The ion pumps will be connected to the manifold via 8” CF flanges. Turbo pump carts will be used to initially pump down the system. The carts will interface with the manifold via a gate valve with 8” CF flanges. A spool piece with four instrument ports, will accommodate an RGA (note that only one module half will have an RGA, the other module half will have a blank at the RGA port), a Convectron gauge, a cold cathode gauge, and a gas pressurization/relief system.

The turbo pump port requires space for both a turbo pump cart and the large gate valve. The gate valve extends out on one side approximately nineteen inches from the port center. The turbo cart specifications mandate thirteen inches of clearance on each side of the port. Hence, the turbo pump port must have thirteen inches of clearance on one side and nineteen inches of clearance on the other side.

Each ion pump port must support a 150 lbs ion pump. The port layout assumed the use of Varian ion pumps, which have a width of ten inches. Hence, five inches of clearance are needed on each side of the port. Physical Electronics manufactures two different 300 l/s ion pumps. One has a width of 8.2”, and the other has a width of 13.3”. Both of these pumps can be used as well. Minor modifications to the manifold layout may be necessary if the wider Physical Electronics pumps are used.

The ports on the instrumentation spool piece use 2.75” CF flanges. To provide adequate assembly room, a clearance of three inches of space on each side of the port center is used in the manifold layout.

Figure 4.2a shows a complete CCL module with two vacuum manifolds and Figure 4.2b shows the details of one vacuum manifold.

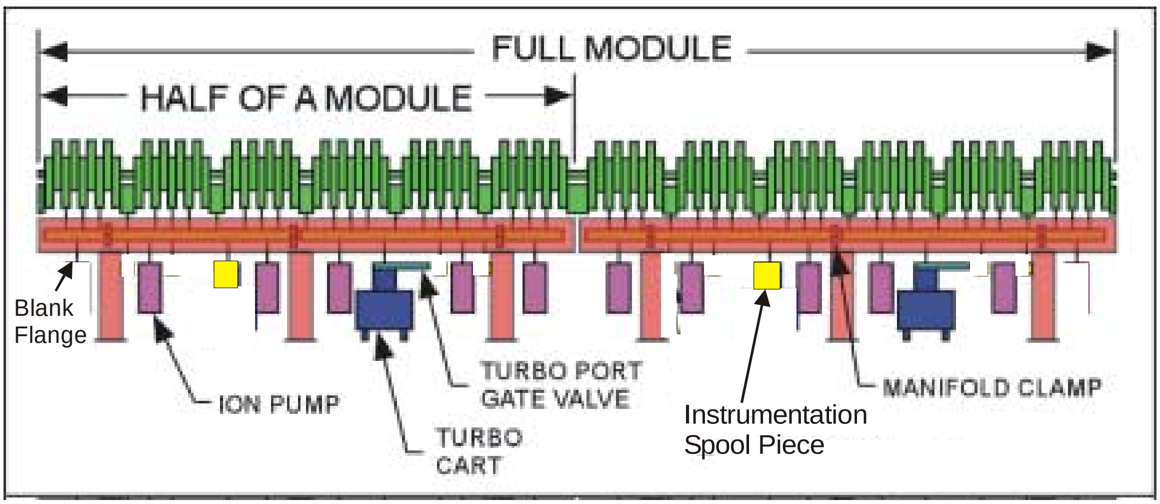


Figure 4.2a: Vacuum manifold layout for a full CCL module.

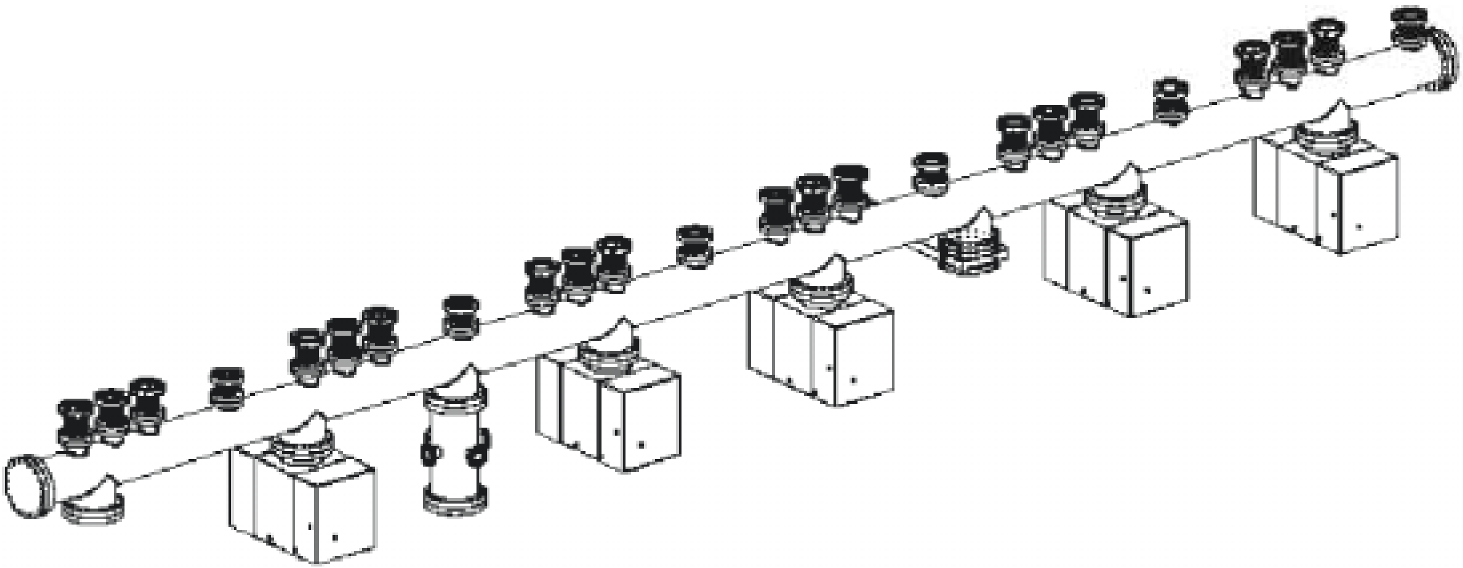


Figure 4.2b. Details of the CCL vacuum manifold.

On the top side of the vacuum manifold are a series of 2.5” ports with 4.625” CF flanges for attaching the vacuum manifold to the side coupling cells and bridge couplers. The distance between the top of the manifold and the bottom of the 4.625” flanges on the side coupling cells is 8.75”, whereas the similar distance between the manifold and bridge couplers is 7.25”. The decision was made to use one bellow design for all of these connections. Consequently, the nipples extending off of the vacuum manifold for the side coupling cells and bridge couplers will have to be of different lengths. These dimensions are shown in Figure 4.3.

The formed bellows design is shown in Figure 4.4. A formed bellows was selected rather than a welded bellows because of the cost implications (a welded bellows is roughly 4 to 6 times more expensive than a comparable formed bellows). Although the flexibility of a formed bellows is less than that of a welded bellows, the lateral offset and compression/expansion limits

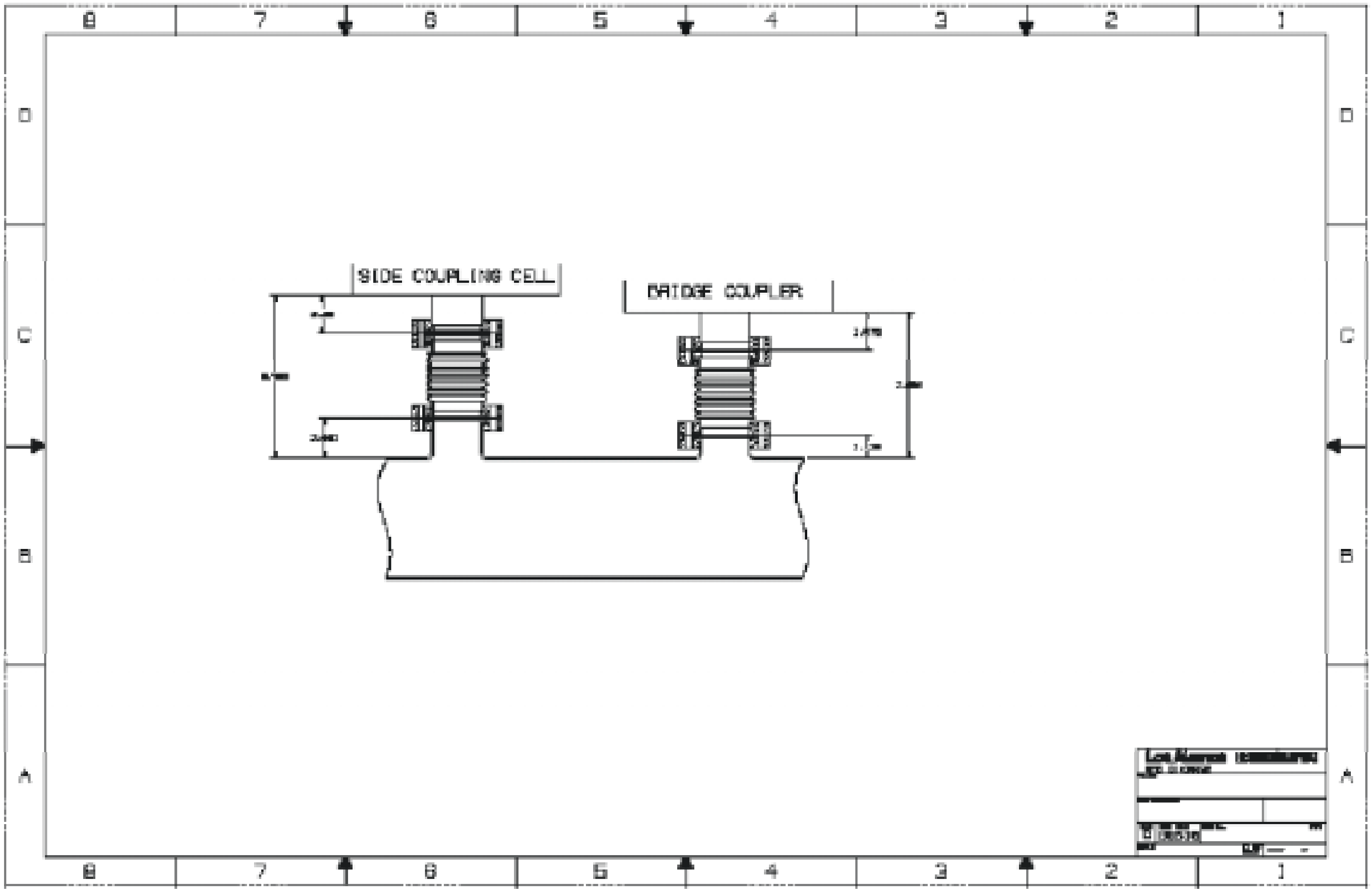


Figure 4.3. Vacuum bellow connections for the CCL side coupling cell and bridge coupler.

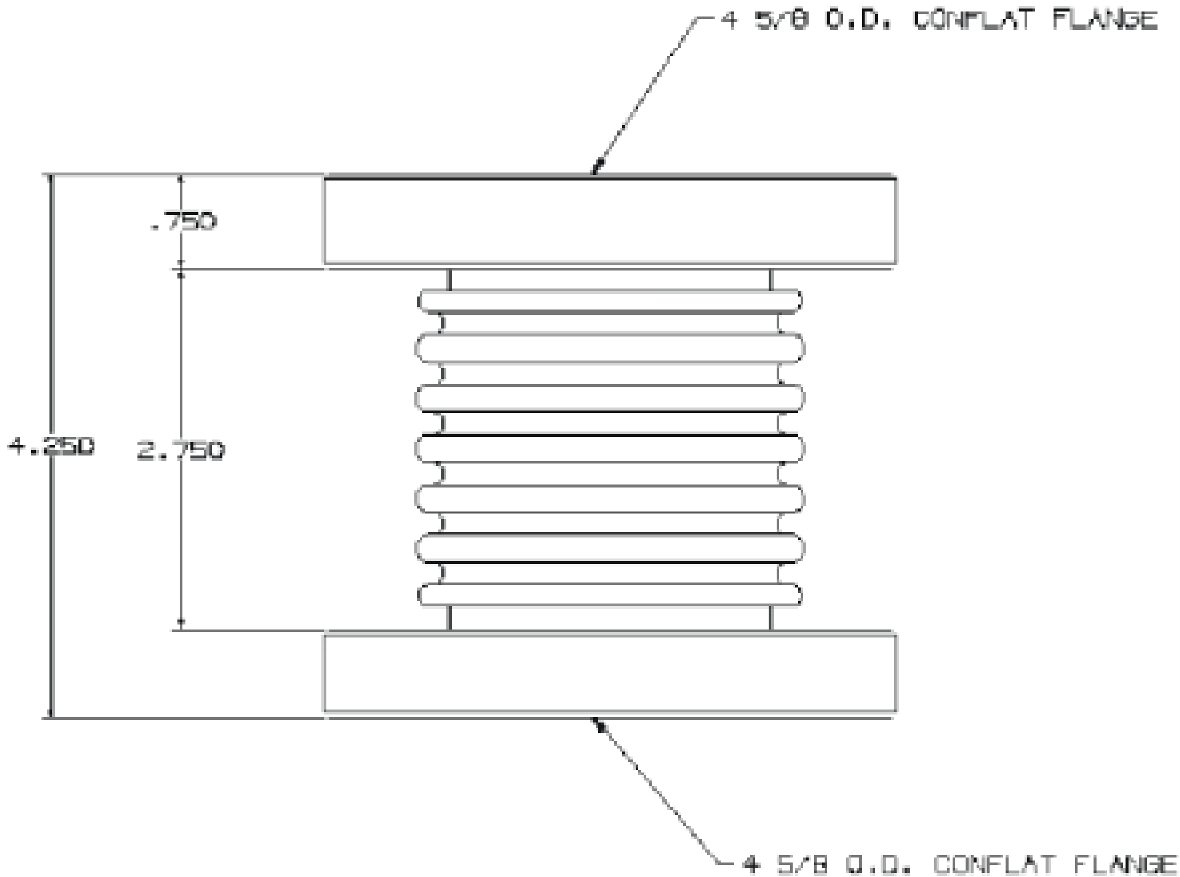


Figure 4.4. Bellows design for the CCL vacuum manifold.

of the bellows shown in Figure 4.4 was determined to be sufficient for the CCL design (see next section on alignment).

As discussed previously, each CCL manifold will cover half of a module. The manifolds will range in length from 4.6 to 6.2 meters. Since there are an odd number of bridge couplers in a module, the two vacuum manifolds for that module will have different numbers of vacuum ports. The first manifold will have twenty four 2.5" and eight 6" ports. The second manifold will have twenty three 2.5" and eight 6" ports.

Due to the length of the manifolds and the large number of ports, it was decided to use pulled joints rather than mitered/welded joints for the ports. The pulled joints are formed by slotting the base tube and inserting a ball die on the internal wall of the base tube. A hydraulic press is used to pull the ball die through the wall of the base tube. This results in a smooth radius and the extruded material is easily faced off for a simple butt weld. The butt weld heats the base tube less because it is further away from the base tube. Figure 4.5 illustrates a finished pulled joint. The base tube diameter 6" and the port tube diameter is 2.5". It is also recommended that the CCL manifolds be electropolished to further reduce their outgassing rate. This entire manufacturing process was followed for the SNS CCL hot model vacuum system manifold with much success.

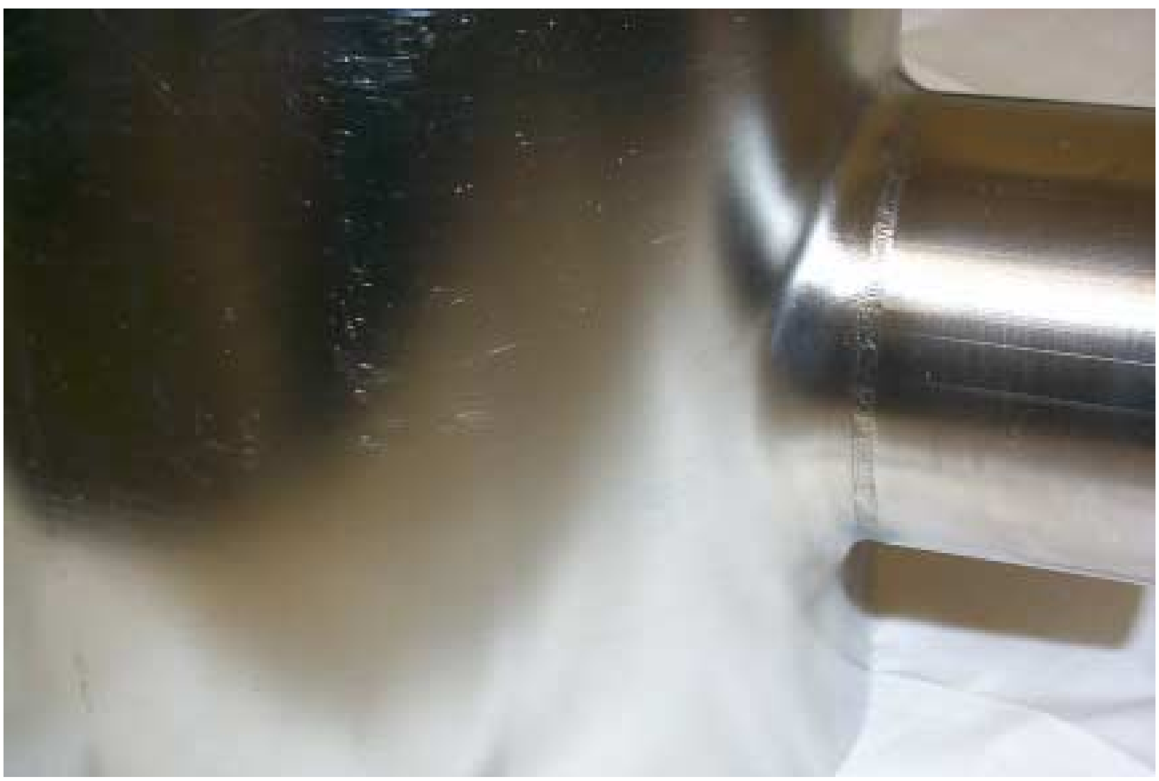


Figure 4.5. Finished pulled joint with butt weld shown.

4.4.2 Mounting and Alignment

Each vacuum manifold (covering half of a CCL module) will be mounted to the CCL support structure in three places with the mounting and alignment fixture shown in Figure 4.6. The two mounts on either end of the manifold will have six degrees of freedom to align the manifold to the CCL support structure. The intermediate manifold mount will have four degrees of freedom to align the manifold in the X and Y directions (perpendicular to the beamline), but no control in the Z direction (parallel to the beamline or axis of the manifold). The movement, of the interior mounts, in the X direction will float to conform to the position of the manifold after it has been aligned. Once the manifold has been satisfactorily positioned, the mounts will be secured to hold the manifold.

The alignment capabilities of the manifold mount are driven by the limited lateral offset of the formed bellows (approximately 10% of the free length, or 0.25”), combined with the uncertainties in the port connection locations on the vacuum manifold and RF structures (due to fabrication limitations). Aligning the manifold relative to the support structure will ensure that the axial offsets of the corresponding port locations on the RF structures and vacuum manifold are minimized. Hence, the amount of lateral deflection that the bellows must experience will be minimized.

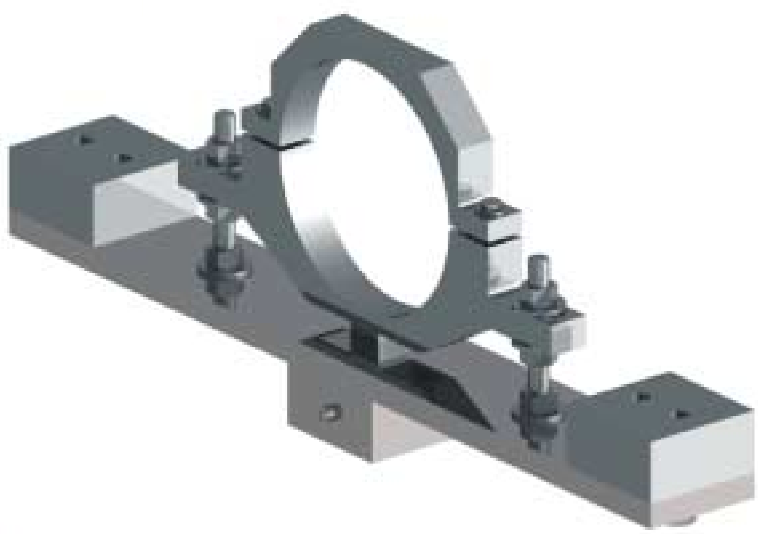


Figure 4.6. Mounting and alignment fixture for the CCL vacuum manifolds.

The vacuum manifold will have two flanges, one on either end that will be used to align it in the direction of the beamline. The flanges will have precision flats machined 90 degrees apart where precision levels can be placed to "clock" the manifold into position. The manifold machining tolerance philosophy is to allow the manifold tube to have a slight contour out of straightness, but the bellows ports that connect to the CCL side coupling cavities and bridge couplers are closely held in a straight line between the precision horizontal flats in both the horizontal and vertical (X and Y) directions. To accomplish this, the penetrations for the bellows will be done after the manifold end flanges and bottom pump ports have been machined. Then the bellows penetrations will be pulled, machined and welded. This will ensure that all of the bellows will be in a straight line even if the manifold distorts slightly during any previous manufacturing steps. The manifold will be aligned to within +- 0.005 inches relative to the beam centerline or any other reference point. This alignment accuracy is required to minimize the lateral displacement of the bellows assembly. The estimate for the required lateral displacement of the bellows flanges is - 0.094 to + 0.138 inches after assembly of the entire system. This displacement comes from adding up the port locating limitations involved in the manufacturing of the CCL segments and vacuum manifold. The lateral displacement of the bellows is + or - 10% of its' free length, which is 2.500 inches. That gives a lateral displacement, flange to flange, of the bellows assembly of + or - 0.250 inches which provides a safety margin of 2:1. The vertical and horizontal flats on the end flanges will be drilled and reamed for a feducial that will be used to align the manifold with a laser alignment instrument.

4.4.3 Strength Issues

The manifold must be capable of safely withstanding gravity loading, pressure loading, and seismic loading. Moreover, the potential buckling of the manifold must be evaluated. In this section, finite element results are presented that validate the structural integrity of the manifold design.

4.4.3.1 Normal Load Conditions

The manifold wall thickness and mounting scheme have been chosen to keep stresses significantly below the yield strength of stainless steel (approximately 35,000 psi) during operation. A manifold with a 0.12 inch wall thickness and three supports currently meets this criterion. This design will avoid permanent deformation of the manifold during operation and assure vacuum integrity. Moreover, the stresses are low enough to eliminate operational fatigue concerns over the thirty-year life span. Figure 4.7 illustrates the expected stress distribution in half of the last manifold on Module 4 under just a gravity load. Figure 4.8 illustrates the expected stress distribution in half of the last manifold on Module 4 under both a gravity load and an external pressure load. The maximum Von Mises stress under just the gravity load is less than 3,000 psi. The maximum Von Mises stress under both a gravity load and a pressure load is less than 5000 psi. In both cases a factor of safety over seven is obtained.

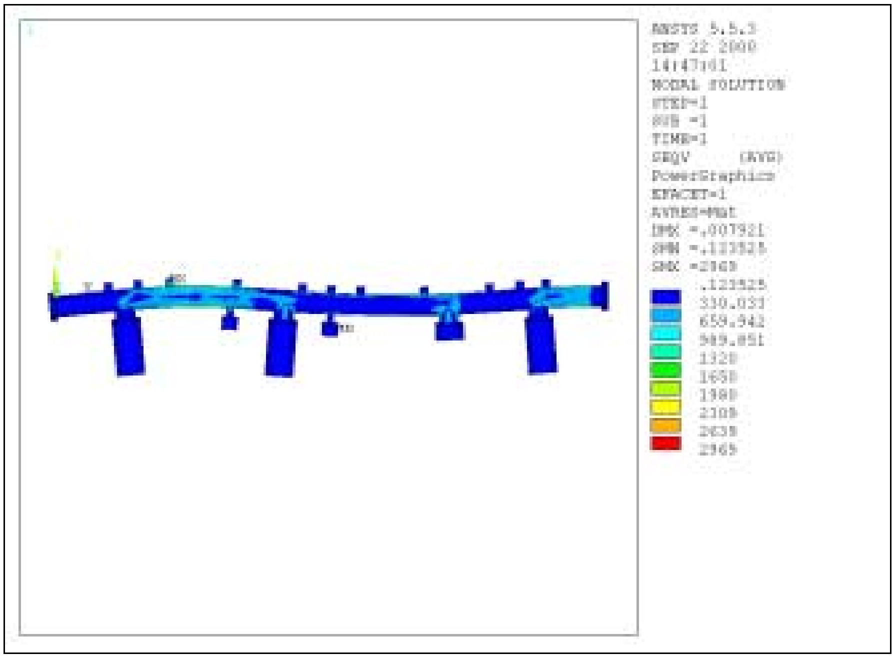


Figure 4.7: Half of the longest manifold under a gravity load.

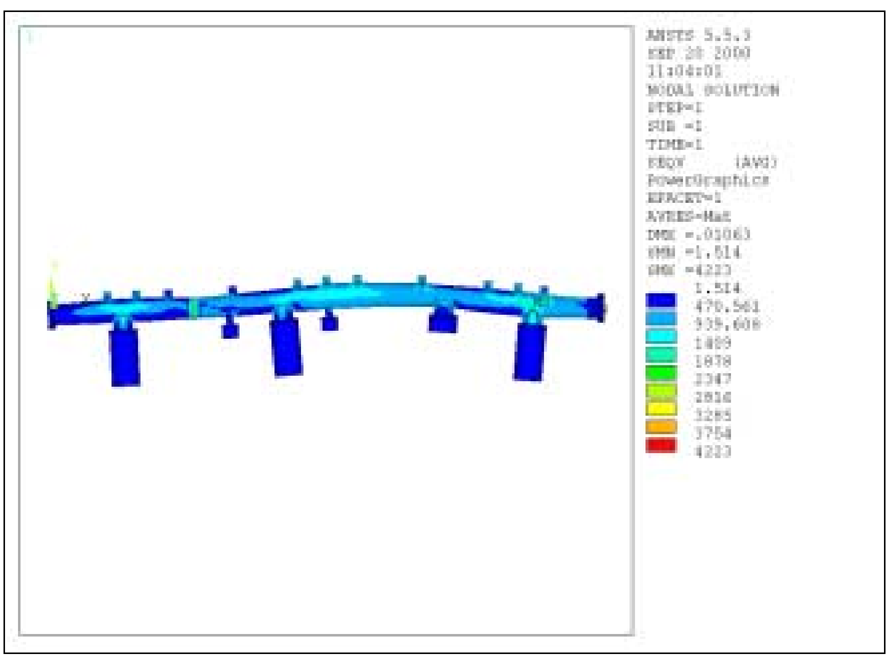


Figure 4.8: Half of the longest manifold under both a gravity load and pressure load.

4.4.3.2 Seismic Load Conditions

During a seismic event, additional loading to the normal gravity and pressure forces will exist. The seismic loads applied to the structure depend on the requirements for the facility. The SNS facility specifies a horizontal seismic load of 0.08g. The natural frequency of the CCL support structure and the manifold are not known. Therefore, amplification factors must be applied to the 0.08g load because the structures may resonate causing higher loads. LINAC structures are considered PC-2 structures. PC-2 structures have an assumed damping ratio of five percent. According to the SNS facility seismic specifications, a five-percent damping ratio results in a maximum amplification of approximately 2.25. Since the two structures – namely, the CCL structure and the manifold – are connected in series the amplification factors must be multiplied. This results in a seismic load at the manifold of 0.08g x 2.25 x 2.25 = 0.4g. This is the maximum seismic load in the horizontal direction. The vertical seismic load is unknown; hence, 0.4g will also be used for that direction. The direction of a horizontal load due to a seismic event is not known. To be conservative a 0.4g load is applied in both horizontal directions (axial & transverse).

Figure 4.9 illustrates the expected stress distribution in half of the last manifold on Module 4 under a gravity load, an external pressure load, and a seismic load. The seismic load consists of a 0.4g axial load, a 0.4g transverse load, and a 0.4g vertical load (1.4g load including gravity). The maximum Von Mises stress under these load conditions is under 8,000 psi. For this worst case loading condition a factor of safety over four is still obtained. Hence, the manifold easily withstands these loads.

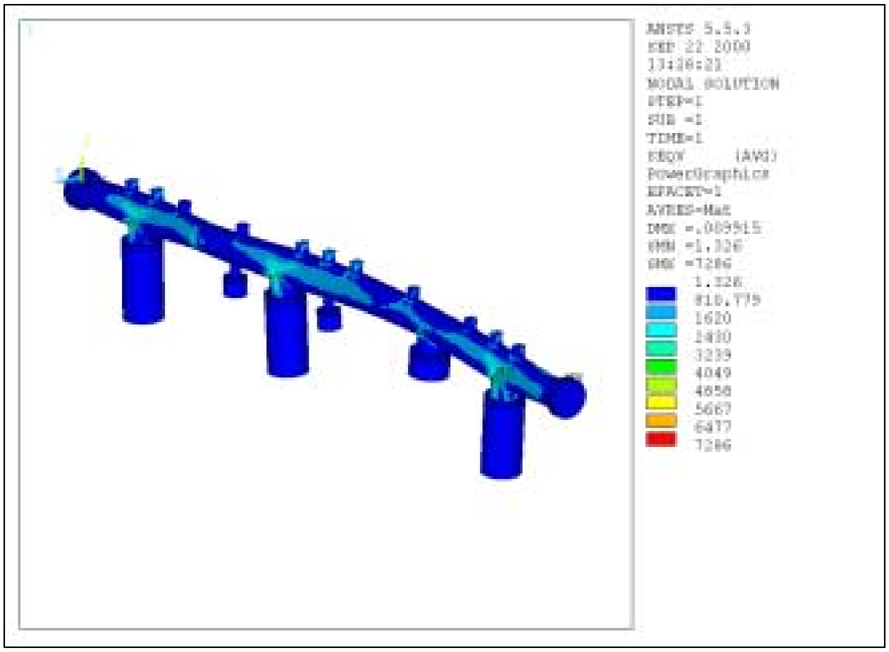


Figure 4.9: Stress results for the seismic loading case.

4.4.3.3 Buckling

After pulling a vacuum on the manifold, buckling of the manifold becomes an issue. Los Alamos National Laboratory has already investigated this issue. The results of that study are described in memorandum ESADE-00-079, "Subject: SNS Hot Model Vacuum Manifold – Structural Stability" (see Appendix I). The conclusion of the memorandum states that an 8-inch stainless steel manifold with a 1/8-inch wall thickness is sufficiently strong. Also, based on these results, a 6-inch manifold with the same wall thickness should be more stable. Therefore, structural stability of the CCL manifolds is not considered to be a problem.

4.5 Ion Pump Mounting

The ion pumps need to be hung from the vacuum manifold. These 300 L/s pumps weigh approximately 150 pounds each, and will thus require a mechanical lifting device to place and hold the pumps while the mounting bolts are attached. Several vendors have been contacted about mounting and supporting ion pumps of this size, and each has indicated that the pumps can simply be hung from their flanges without additional support. In addition, the CCL vacuum manifold is rigid enough that the weight of the vacuum pumps will not cause significant stresses or deformations. The design or selection of a mechanical lifting device will be reserved for the ORNL/SNS vacuum or operations team, so that a common device is chosen that can meet the installation needs of vacuum pumps throughout the facility.

4.6 Vacuum Loading Influence on CCL RF Structure

Each CCL segment consists of eight accelerating cells coupled together with seven off axis coupling cells. The segment is arranged so that the four odd numbered coupling cells are positioned above the beam axis and the three even numbered coupling cells are positioned below. The vacuum system interfaces to the CCL segment through three vacuum ports, one on each of the lower coupling cells. A bellows assembly structurally isolates each vacuum port from the common module vacuum manifold.

The isolating bellows are not arranged opposite each other in order to balance their induced vacuum loads. The system is configured with vacuum bellows below the CCL segment only. This arrangement causes a net vertical load to act on the CCL segment when under vacuum. This load is equal to the product of the external atmospheric pressure and the sum of the cross-sectional areas of each bellows.

Of concern is local deformation in the vicinity of the vacuum ports as well as aggregate segment bending due to the asymmetric port loads. Detailed finite element models of assorted CCL half-cells have been created to evaluate various structural load cases. Local deformation due to the vacuum port was evaluated with a finite element model of a 42% beta half-cell. The model with superimposed displacement results is depicted in Figure 4.10. The half-cell is oriented upside down with the vacuum port facing up in the figure. Lateral symmetry with respect to the beam axis permitted modeling of only one half of the half-cell. Appropriate boundary conditions were applied to the forward and aft faces as well as half-cell bisecting symmetry plane. The color contours represent vertical displacement in inches. The calculated local deformation near the vacuum port is less than 10 micro-inches.

Figure 4.10. Beta 42% CCL half-cell vertical displacement due to vacuum loading.

Additional calculations were completed in order to estimate CCL segment deformation due to the asymmetric vacuum port loads. Simple calculations based on approximate bulk segment section properties were utilized. The very rigid CCL segment structure is minimally affected by loads of this magnitude. The calculated maximum displacement of the segment axis due to the three port loads is also less than 10 micro-inches.

The calculated deformation due to the vacuum port loads, both locally near the port and for the whole segment are very small. Displacement values of this magnitude are well below manufacturing and alignment tolerances and thus are not of concern with respect to accelerator performance.

5.0 Instrumentation and Controls

5.1 Introduction and Design Requirements

The design of the instrumentation and control system for the SNS CCL vacuum system will be based on the design of the SNS DTL vacuum system. These two systems utilize an instrumentation and control system that will be based on lessons learned from the APT/LEDA RFQ vacuum system [5.1]. The two vacuum systems will be in full compliance with SNS standards for hardware and software.

As with the DTL vacuum control system, each CCL module vacuum control system will be required to operate as a stand-alone system. Each CCL module vacuum control system will also be required to interface with the global control system, EPICS.

The design of the CCL vacuum systems uses ion pumps connected to a manifold, which in turn is connected to the coupling cavities. A scroll pump and turbomolecular pump mounted on a pump cart will connect to the manifold and will be used to pump down the system from atmosphere to a pressure where the ion pumps can be started without overheating the pump or causing internal electrical discharges. There are 4 modules in the CCL and the vacuum system and each module will have a sector gate valve to isolate it from its neighboring modules. One PLC will control each module vacuum system.

The SNS naming convention as found in the document "SNS Device and Signal Naming Convention, Release 1.0, SNS 102000000-SR0001-R00" will be followed for all equipment and their associated signals throughout the CCL vacuum system.

The P&ID for the CCL Module 1 vacuum system is shown in Fig. 5.1.

The control system will monitor the status of the vacuum system and use interlocks to ensure proper operation of the vacuum system. In the event of a vacuum system malfunction, interlocks will be available to the RF system to shutdown RF power to the cavities.

During a power failure, the vacuum system will shut down. When power is restored, the control system will reboot, but will not restart the vacuum system. The state of the vacuum system will have to be determined by an operator who will then use the control system in a manual mode to restart the vacuum pumps. If a reasonable vacuum condition still existed after a power failure, the ion pumps could be restarted immediately and high vacuum could be re-established very quickly.

Figure 5.1 P&ID for CCL Module 1

5.2 *Instrumentation and Control System Architecture*

The control system for the CCL vacuum will consist of a local control system that will be implemented using a Programmable Logic Controller (PLC). A PC running Windows NT 4.0 will be required during the development phase to run the configuration and ladder logic software for the PLC. The PC will also be needed after development and installation if the configuration changes or the ladder logic needs to be updated.

The primary operating mode is for the PLC to communicate via Ethernet to an EPICS IOC (Input/Output Controller). The IOC is a VME crate with a PowerPC processor running VXWorks. The IOCs form part of the backbone of the global control system, EPICS. The PLC can also operate in a stand-alone mode. The stand-alone mode will be used for initial testing and commissioning in the RATS building. This mode will also be useful after commissioning in the event EPICS is not running. A block diagram of the vacuum control system is shown in Figure 5.2.

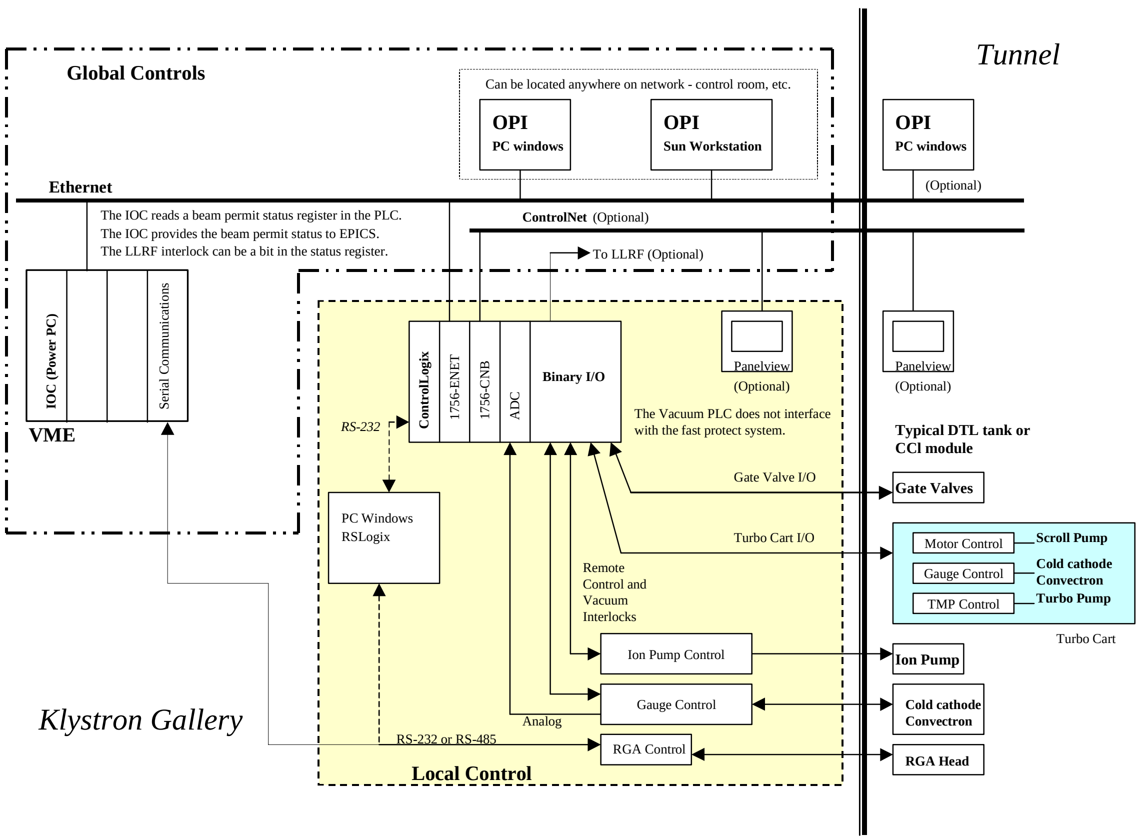


Figure 5.2. Block diagram of the CCL vacuum control system for module 1

The SNS collaboration will use Allen-Bradley ControlLogix as the standard for PLCs. RSLogix from Allen-Bradley is a programming environment that runs under Windows NT and is used to configure and program the ControlLogix PLC. The CCL vacuum control system shown in Figure 5.2 adheres to all current SNS standards.

Allen-Bradley PanelView operator terminals will be used to provide a graphical user interface to the local control PLC in the stand-alone mode for the CCL vacuum system. Functions such as starting and stopping a pump or opening and closing a valve will be represented by graphical pushbuttons on the PanelView touchscreen.

Allen-Bradley PanelBuilder32 software will be used to configure the PanelView operator terminals. Software tools are provided to create objects and symbols that can be cut and pasted to generate a graphical user interface. In Figure 5.2.1, ControlNet is shown as communications link to the PanelView operator terminals. Currently, PanelView does not support Ethernet communications. Allen-Bradley is expected to release Ethernet compatible PanelView operator terminals in the near future, eliminating the need for ControlNet.

The control system can be quickly prototyped and debugged under RSLogix. During installation, the operator will use the graphical user interface on the PanelView operator terminal to operate the CCL vacuum system in the stand-alone mode. After installation, the CCL vacuum system will be integrated with EPICS. EPICS will command the PLC and provide a graphical user interface. The PLC will still do the actual control of the pumps and valves and will not differentiate if a command came from the PanelView operator terminal or EPICS. Eventually, a laptop computer can be used anywhere there is an Ethernet port to access EPICS, reducing the need for PanelView operator terminals

The vacuum pump and ion gauge controllers will have programmable set points and alarms that will be passed directly to the PLC. The setpoints and alarms will be used by the PLC for interlocks. Interlock logic within the PLC will prevent the operator from selecting an improper valve or pump operation.

Many ion and turbo pump controllers have optional RS-232 interfaces. However, this would require a separate RS-232 interface from the control system to each pump. Each different type of pump controller would require a specific driver to be developed. Also, PLCs are not designed control equipment with serial communications. The IOC could effectively handle the serial communications, but then the interlock logic would have to reside in the IOC, essentially eliminating all the benefits of the PLC.

In comparison, if a simple contact closure/setpoint type interface is used, a single PLC could handle several dozen pumps rather than a large serial communications network with a dedicated port for each individual ion pump controller. The current design is based on contact closure/setpoint type interfaces. More importantly, the interlock logic resides in the PLC.

Since the turbo pump cart will only be used during the initial pumpdown or in the case of a leak that the turbo can overcome, the pump cart controls will only be connected temporarily. The turbo pump cart will have its pump controllers and instrumentation resident on the cart. An interface cable from the PLC will connect to the pump cart. Each pumpdown port will have its own pump cart interface cable. The control system will determine which locations have pump carts attached by the cable connection. All pump cart functions will be controlled by the PLC. The pumpdown port will have an electro-pneumatic gate valve that will be controlled by the PLC. This will insure that the operation of the pump cart and the pumpdown port gate valve are properly interlocked.

Each CCL module has two RF windows; each will use a NEG pump, a small turbo and a small scroll pump. The NEG pump is completely passive and does not require active control like a turbo. However, a NEG must be activated and periodically regenerated under vacuum at high temperature (450° C) for 45 minutes. This requires a heater element incorporated in the NEG pump housing, a heater power supply/controller and an auxiliary pumping system mounted on the NEG pump housing.

The PLC will use a digital to analog converter (DAC) to provide a setpoint to the NEG heater controller. The PLC will read back the temperature of the heater and control the activation/regeneration time.

A small turbo and scroll pump will provide sufficient pumping speed for the activation/regeneration. Vacuum pressure, NEG temperature and power supply current will be used as interlocks to safely activate or regenerate the NEG.

Although vacuum pressure can be derived from ion pump current, there is a need to measure vacuum pressure before the ion pumps are started. An ion pump operates more efficiently if it can be started at a moderately high vacuum (approximately 1×10^{-5} Torr). Starting an ion pump at higher pressures causes the pump to overheat or generate internal electrical discharges and reduces the pump's operating life. To provide the most robust control system, an independent ion gauge is required to determine if the turbo cart has pumped out the CCL to a sufficient vacuum condition.

The SNS collaboration will use the cold cathode type ion gauge to measure vacuum pressures. Cold cathode ion gauges are simple and inexpensive, but not as accurate as some of the newer types of hot filament ion gauges. The SNS collaboration has decided that the higher cost, high accuracy hot filament ion gauges are not necessary in the linac or ring vacuum systems.

The cold cathode ion gauge will be an inverted magnetron. The inverted magnetron will be used rather than a penning type cold cathode gauge because it has a more linear response and can measure pressure over a wider range of vacuum.

The RF window vacuum interlock (an alarm sent from the vacuum system to the LLRF controls when the vacuum exceeds 10^{-6} Torr) should be less than 16 milliseconds. In event of a vacuum failure, the 16 millisecond delay would allow only one RF pulse, at most to enter the Linac before the RF is shut down.

All ion gauges must integrate the raw signal over some period of time, otherwise the output signal would fluctuate too much to be useful. Some controllers integrate over a short period of time, around 10 milliseconds, others integrate over 100 milliseconds. A response time of less than 10 milliseconds is stated as part of the gauge controller specification.

Note that most gauge controllers have a trimpot on the controller that must be manually adjusted for the trip point. In LEDA, a software programmable trip point was required to speed up the conditioning of the RF window. Higher pressures could be set from the control room for initial conditioning at low power.

For LEDA, the analog signal from the gauge controller (10 ms delay) was sent to a fast analog to digital converter in the IOC. It was very easy to program a software programmable trip point in the IOC. The IOC would then set a bit on a digital output card and this was wired directly to the LLRF. The total delay was never accurately benchmarked and probably exceeded 16 milliseconds.

The 16 millisecond requirement can be met by hard wiring the vacuum alarm trip point directly from the cold cathode to the LLRF controls. Other options are still be explored. The ion pump controller developed by JLAB is one option being considered. The controller does not use very much integration time and has a 2 ms response. Instead of a cold cathode gauge on the RF window, a small ion pump could be used as a gauge. (A cold cathode and small ion pump operate on essentially the same principal.)

A convection type gauge rather than a thermocouple or Pirani gauge will be used to measure the pressure during pumpdown from atmosphere to the milliTorr range in each CCL module. A thermocouple or Pirani gauge measures heat loss only by conduction from the gas molecules. This limits their measurement range from 1 milliTorr to about 2 Torr. At higher pressures, heat loss by convection becomes a greater factor. A convection type gauge is more accurate at atmospheric pressures than a thermocouple gauge or Pirani gauge because it measures heat loss by convection by using a temperature compensated heat sensor and precisely controls the power delivered to the heating element. Convection type gauges include a conductive heat loss measurement at the lower pressures.

One convection type gauge will be used to monitor the foreline pressure of the turbo pump on the pump cart. It will provide an interlock to the PLC to protect the turbo from high foreline pressures. A cold cathode gauge will be mounted near the inlet of the turbo on the pump cart. This will provide a high vacuum interlock to protect the turbo. The cold cathode gauge will also give a positive indication that the turbo is functioning properly before its gate valve can be opened to the CCL if the module is under vacuum.

A quadrupole type residual gas analyzer without an electron multiplier will be used to measure the partial pressure of gases in each CCL module. Modern quadrupole RGAs have digital signal processors and synthesized RF drives which results in higher sensitivities with the standard faraday cup detector. Electron multipliers only provide additional sensitivity when used in ultra high vacuum, but are probably not needed at the typical operating vacuum pressures in the CCL.

Modern quadrupole RGAs have compiled stand alone applications that run on a PC under Windows. The RGAs utilize serial communications link to a PC. However, for entire accelerator, it is not practical to have dozens of PCs in the control room, each controlling only a few RGAs. Also, the RGA application has no provision to synchronize its data with EPICS.

With this volume of RGAs, SNS will require access to the source code. The following functions will be ported to EPICS:

1) Start function: starts communications, assigns an instrument ID (similar to file ID), turns on the emissions, waits a few seconds and checks for errors. An error structure is returned.
2) Sequential scan function: acquire a spectrum from 0 to 100 amu. (0 to 100 amu is an example, can be programmed for any range of masses.). A structure is passed to the RGA that has the starting and ending masses and parameters such as points per amu and dwell

time. A binary array is returned with amu versus ion intensity. An error structure is also returned.

3) Random scan function: default mode for the RGA. A structure is passed to the RGA with all the necessary parameters. A random scan usually only looks at specified masses rather than the whole spectrum. A data structure and an error structure are returned. Leak checking could be done with this function by only looking at mass 4 at a very fast rate.

4) Close function: turn off emissions and terminate communications.

By porting these to EPICS the RGA data will be timestamped and archived by EPICS. The data can be easily accessed by any operator screen and correlated with any data or event in the EPICS database.

Other functions such as tuning or calibrating will be handled by taking a laptop computer running the RGA application and connecting directly to the RGA. These functions are not required very often with modern RGAs. Also, since SNS will use RGAs with only faraday cup detectors, many of the functions in the RGA software will not be required since they are used for setting up and calibrating the electron multiplier.

From Section 4.2, the total cumulative radiation dose was calculated to be 4.3×10^6 Rads at the high energy end of the normal conducting linac. Table 5.1 lists the radiation damage (cumulative radiation dose) limits for common materials used as electrical insulation in cables [4.2, 4.6].

Table 5.1. Radiation damage limits for electrical insulating materials[4.2, 4.6].

Material	Cumulative Dose Limit (Rad)
Polyether Ether Ketone (PEEK)	3×10^9
Polyethylene (PE)	8×10^7
Polyvinylchloride (PVC)	1×10^8
Polychloroprene Rubber (Neoprene)	8×10^7
Silicone Rubber (SIR)	9×10^6
Styrene-Butadiene Rubber (SBR)	4×10^7
Butyl Rubber	5×10^6
Tefflon (PTFE)	1×10^5
Nylon	1×10^7

The high voltage cable that Varian supplies with its ion pumps uses Polyether Ether Ketone (PEEK) as its insulation. From Table 5.5.1, the use of PEEK will be acceptable in the normal conducting linac. Polyvinylchloride (PVC) and Polyethylene (PE) are two very common insulators in electrical cables. Many high voltage coaxial cables and multiconductor twisted pair cables use one or both of these materials. Table 5.5.1 shows that these two materials are also acceptable in the normal conducting linac.

Because a large number of commercially available electrical cables are made of materials that are acceptable for use in the normal conducting linac, the selection of cables should not present any problems.

5.3 Control Methodology and Logic

The primary requirement of the CCL vacuum control system software is to interface to the global control system, EPICS. This requirement will be met by adhering to SNS standards and providing good documentation.

While the LEDA/RFQ vacuum system utilized a different PLC, the ladder logic in the PLCs that describes the sequence of switch closures, interlocks and process control setpoints that have to be executed in order to energize a valve or start a vacuum pump will be very similar. The LEDA/RFQ vacuum system successfully demonstrated that the ladder logic for the local control system can be developed at a remote site and then integrated with EPICS at the facility.

A ladder logic fragment from a vacuum system that was built at LLNL is shown in Appendix F. The ladder logic is solved in a specific sequential order and coils from one function are used as interlocks in the next function. The ladder logic structure is in essence, a flow chart. For example, to open the foreline valve (SV6) to the turbo, scroll pump P7 must have been started in the previous function and must be currently running. If the scroll pump were to experience a thermal overload and shut down the foreline valve be forced to close too.

There are five functions the ladder logic example. They are:

1. Start the roughing pump - interlock will shut down pump if there is a thermal overload
2. Open the foreline valve to the turbo - scroll must be running
3. Start the turbo - foreline valve must be open, pressure must be adequate and there are no faults in the turbo pump controller
4. Open main gate valve - vessel can be roughed down through the turbo if the turbo is in start mode and pressure in the vessel is not too low. Also, the main gate valve can be opened if the vessel is in a high-vacuum condition when the turbo is running at full speed.
5. Start the ion pump if the vessel is at high vacuum and there are no faults in the ion pump controller

These five functions are examples from an operational vacuum system. Some of these functions will need only slight modifications to be re-used in the operation of the CCL vacuum system.

5.4 Safety Interlocks and Equipment Protection

An analysis of possible vacuum system failures, the probability of that failure, its common symptoms and the PLC interlock response to protect the equipment and/or personnel is shown in Table 5.2.

Table 5.2. Analysis for PLC Interlock Response for CCL Vacuum System Failures

System	**Failure or Condition**	**Probability**	**Symptom**	**PLC Interlock Response**
Ion Pump	Insulator high leakage current or shorted by sputtered titanium	Low - insulator is shielded	High pump current	Ion pump controller will shut down pump and indicate a fault. PLC sends ion pump fault message to global control. Single ion pump failure does not cause immediate shutdown in beam. Ion gauges monitor pressure. If pressure rises too high, PLC interlock will send pressure fault message to global control.
	Anode to cathode short	Low -large amounts of conductive/magnetic particles would be needed to cause short	High pump current or short circuit	Same as above
	High voltage feed through failure	Low/med - usually results from physical damage	No pump current	Same as above
	High voltage cable failure open circuit	Low/med - usually results from physical damage	No pump current	Same as above
	High voltage cable failure short circuit	Low/med - usually results from physical damage	High pump current	Same as above
	Pressure too high	Med - Turbo carts have not pumped out DTL/CCL to a sufficient vacuum	Pressure too high to start ion pumps	Ion gauges monitor pressure. If pressure is too high, PLC interlock will prevent ion pumps from being turned on. Beam permit interlock from PLC will not be set.
	Pressure initially good, then rises above setpoint	Low/Med - very high gas load created by RF or beam or mechanical failure (a leak is created), ion pumps cannot overcome	Pressure too high	Ion gauges monitor pressure. If pressure climbs too high, PLC interlock will shutdown ion pumps. PLC interlock will send pressure fault message to global control.
	Ion pump end-of-life	Low - over 60,000 hours of operation - cathode sputtered through	Low base pressure Pump instability	Ion gauges monitor pressure. If pressure climbs too high or pressure burst, PLC interlock will shutdown ion pumps. PLC interlock will send pressure fault message to global control.
Vacuum Vessel - Manifolds, bellows, tanks, modules	Vacuum system leak	Low/med - Proper handling and installation will prevent leaks in joints and seals. Components will be leak checked before installation.	Cannot rough-down or takes a long time to rough-down Low base pressure	If extremely large leak during rough-down, scroll pump will overheat. Motor control circuit will shutdown the scroll pump and send fault signal to PLC. If large leak during rough-down, turbo will not spin up to normal RPMs. Turbo controller will shutdown and send fault signal to PLC. If turbo cannot base system below $1x10^{-5}$ Torr, a programmable timeout in PLC will send warning message to global control. If ion pumps do not reach expected base pressure, PLC will send high pump current/low vacuum warning message to global control

System	Failure or Condition	Probability	Symptom	PLC Interlock Response
Turbo cart	Scroll pump head failure	Low/med - failures are usually due to lack of periodic maintenance (every 10,000 hours)	Low base pressure Low pump speed	Vacuum gauge monitoring foreline pressure PLC interlock will shutdown scroll pump PLC interlock will shutdown turbo PLC interlock will close turbo gate valve to protect DTL/CCL vacuum PLC sends turbo cart fault message to global control
	Scroll pump motor failure or short to ground	Low/med - motor bearing or winding failure uncommon Wiring error or failure	High motor current or windings open or short	Motor control circuit (or circuit breaker) will shutdown the scroll pump and send fault signal to PLC PLC interlock will shutdown turbo PLC interlock will close turbo gate valve to protect DTL/CCL vacuum PLC sends turbo cart fault message to global control
	Scroll pump gas load too high	Low/med - vacuum system leak or contamination	High motor current	Scroll pump will overheat, motor control circuit will shutdown the scroll pump and send fault signal to PLC PLC interlock will shutdown turbo PLC interlock will close turbo gate valve to protect scroll pump PLC sends turbo cart fault message to global control
	Turbo pump bearing failure	Low - modern ceramic bearings are very reliable	High motor temp High motor current	Turbo controller will provide safe shutdown and send fault signal to PLC PLC interlock will close turbo gate valve to protect DTL/CCL vacuum PLC sends turbo cart fault message to global control
	Turbo rotor crash	Low - Unless turbo ingests foreign object or is subject to multiple atmospheric vents while operating at full speed	Sudden drop in RPMs	Turbo controller will shutdown pump and send fault signal to PLC PLC interlock will close turbo gate valve to protect DTL/CCL vacuum PLC sends turbo cart fault message to global control
	Turbo gas load too high	Low/med - vacuum system leak or contamination	High motor current	Turbo controller will provide safe shutdown and send fault signal to PLC PLC interlock will close turbo gate valve to protect turbo PLC sends turbo cart fault message to global control

System	Failure or Condition	Probability	Symptom	PLC Interlock Response
RF Window	High pressure or contamination causing RF breakdown	High - mainly during conditioning	RF arcs Pressure bursts	Vacuum gauge monitoring RF window pressure will send analog value directly to LLRF as feedback Extremely large pressure burst will cause PLC interlock to shutdown ion pumps. PLC interlock will send pressure fault message to global control
	NEG Pump failure	Low - no moving parts or high voltage NEG could become completely saturated with extended use or high gas load due to vacuum system leak or contamination	Low base pressure in RF window	Vacuum gauge monitoring RF window pressure. PLC interlock will send RF window pressure fault message to global control.
	NEG Pump regen - Heater failure	Low - heater element failure uncommon	NEG fails to reach correct regen temp	Thermocouple monitors regen temperature. PLC interlock will send regen fault message to global control
	NEG Pump regen - Scroll pump head failure	Low/med - failures are usually due to lack of periodic maintenance (every 10,000 hours)	Low base pressure Low pump speed	Vacuum gauge monitoring foreline pressure PLC interlock will shutdown scroll pump PLC interlock will shutdown turbo PLC interlock will close turbo gate valve to protect RF window vacuum PLC interlock will shutdown NEG regen PLC sends fault message to global control
	NEG Pump regen - Scroll pump motor failure	Low - motor bearing or winding failure uncommon	High motor current or windings open or short	Motor control circuit (or circuit breaker) will shutdown the scroll pump and send fault signal to PLC PLC interlock will shutdown turbo PLC interlock will close turbo gate valve to protect RF window vacuum PLC interlock will shutdown NEG regen PLC sends fault message to global control
	NEG Pump regen - Turbo bearing failure	Low - modern ceramic bearings are very reliable	High motor temp High motor current	Turbo controller will provide safe shutdown and send NEG regen turbo fault signal to PLC PLC interlock will close turbo gate valve to protect RF window vacuum PLC interlock will shutdown NEG regen PLC sends fault message to global control
	NEG Pump regen - Turbo rotor crash	Low - Unless turbo ingests foreign object or is subject to multiple atmospheric vents while operating at full speed	Sudden drop in RPMs	Turbo controller will shutdown pump and send NEG regen turbo fault signal to PLC PLC interlock will close turbo gate valve to protect RF window vacuum PLC interlock will shutdown NEG regen PLC sends fault message to global control
	NEG Pump regen - Turbo gas load too high	Med. - NEG regen temp too high or vacuum system leak or contamination	High motor current	Turbo controller will provide safe shutdown and send NEG regen turbo fault signal to PLC PLC interlock will close turbo gate valve to protect turbo PLC interlock will shutdown NEG regen PLC sends fault message to global control

System	Failure or Condition	Probability	Symptom	PLC Interlock Response
Sector Isolation Valves	Opening Sector Isolation Valve between tanks or modules	Normal operation	Cannot open Sector Isolation Valves due to large difference in pressure between tanks or modules	Vacuum gauges monitoring the pressure in an upstream tank or module indicates low vacuum. PLC interlock to downstream module or tank will not allow downstream PLC interlock to open valve.
	Isolation valve between tanks or modules is open, then a large pressure difference develops	Low/med - higher pressure or a burst of gas could develop in a tank or module under during operations such as beam conditioning	Sector Isolation Valve closes	Vacuum gauges detect a rise in pressure to an unacceptable level in a module or tank. PLC will close its upstream Sector Isolation Valve and send low vacuum interlock to PLC controlling downstream tank or module. Downstream PLC will close its valve and both PLCs send valve closed message to global control. Upstream PLC also sends low vacuum message to global control.
I&C	Low vacuum gauge failure	Low - gauge is probably not connected or damaged	No reading	Gauge controller will not close the gauge's process control setpoint. PLC interlock will not let rough-down proceed. Can switch to redundant gauge and resume rough-down
	High vacuum gauge failure	Low/med - gauge not connected or contaminated Cannot start gauge at high vacuum	No reading	Gauge controller will not close the gauge's process control setpoint. Gauge controller may indicate a fault. With redundant gauges and ion pump currents monitoring pressure, PLC can be programmed to ignore a single faulty gauge.
	Valve failure	Low - Turbo gate valve and sector isolation valves will not be cycled very often	Solenoid energized, but position indicator does not show valve open	If PLC does not read valve position open within 5 seconds of energizing solenoid, the solenoid is de-energized and the valve reverts back to its normally closed position.
	PLC failure	Very low - PLCs are designed for very high reliability in harsh industrial environments	Various	PLC can be powered by UPS in case of power outage PLC has extensive built-in self diagnostics Watchdog timer can alert global controls if PLC is not operating If an I/O module is defective, it can be hot-swapped

5.5 Signal/Device Naming Conventions

The SNS standard for device and signal naming [5.4] was used to create a device and signal list that defines all the I/O channels and internal commands for the PLC. This device and signal list will be used in creating the EPICS database. The device and signal list for CCL module 1 is shown in Appendix D. The device and signal list for all four CCL modules is available as an Excel spreadsheet.

6.0 SNS Facility

The design of the CCL vacuum system requires multiple mechanical and electrical interfaces with the SNS facility. Figure 6.1 shows a plan view of the portion of the SNS facility corresponding to the drift tube linac. The CCL portion of the facility is divided into two main structures; the linac tunnel, containing the CCL RF structures, vacuum pumps, and instrumentation, and the klystron gallery, containing the klystron and RF power systems, water skids, motor control centers, electronics racks, etc. Figure 6.2 shows a cross-section of the CCL facility structures. Running between the linac tunnel and klystron gallery are a number of concrete chases, which carry in part, vacuum pump and instrumentation power lines and diagnostic cabling. Each of these facility structures, and their various interfaces with the CCL vacuum system, is described in more detail in the following sections.

6.1 Klystron Gallery

The klystron gallery is 30 ft wide by 26 ft high and contains much of the hardware and electronics for the various linac support systems (RF controls and power systems, water cooling and resonance control, vacuum, etc.). In particular, the klystron gallery houses eight electronics racks for the CCL vacuum system. Each electronics rack contains the vacuum pump and instrumentation power supplies/controllers as well as a PLC and touch screen interface to form a complete and stand-alone control system for a single CCL module vacuum system. As shown in Figure 6.1, the vacuum system electronics racks are distributed throughout the klystron gallery. The power and signal lines will run to and from the electronics racks and chases from overhead cable trays. Concrete shielding blocks located at the openings of the chases, as well as a multitude of overhead cable trays and junction boxes, will dictate the exact routing of the power and cable lines. The cable tray routing and junction box locations still need to be defined with SNS conventional facilities.

6.2 Linac Tunnel

The linac tunnel is 14 ft wide by 12 ft high and contains the four CCL RF structures and the associated vacuum pumps and instrumentation. As shown in Figure 6.3, the proton beam line is 50 inches above the floor and 68 inches from the South wall. The CCL support structure has a ground clearance of 23 inches and has a 4-foot spacing to the South wall. The vacuum system cabling to/from the electronics racks will enter the Linac tunnel at the base of the South wall

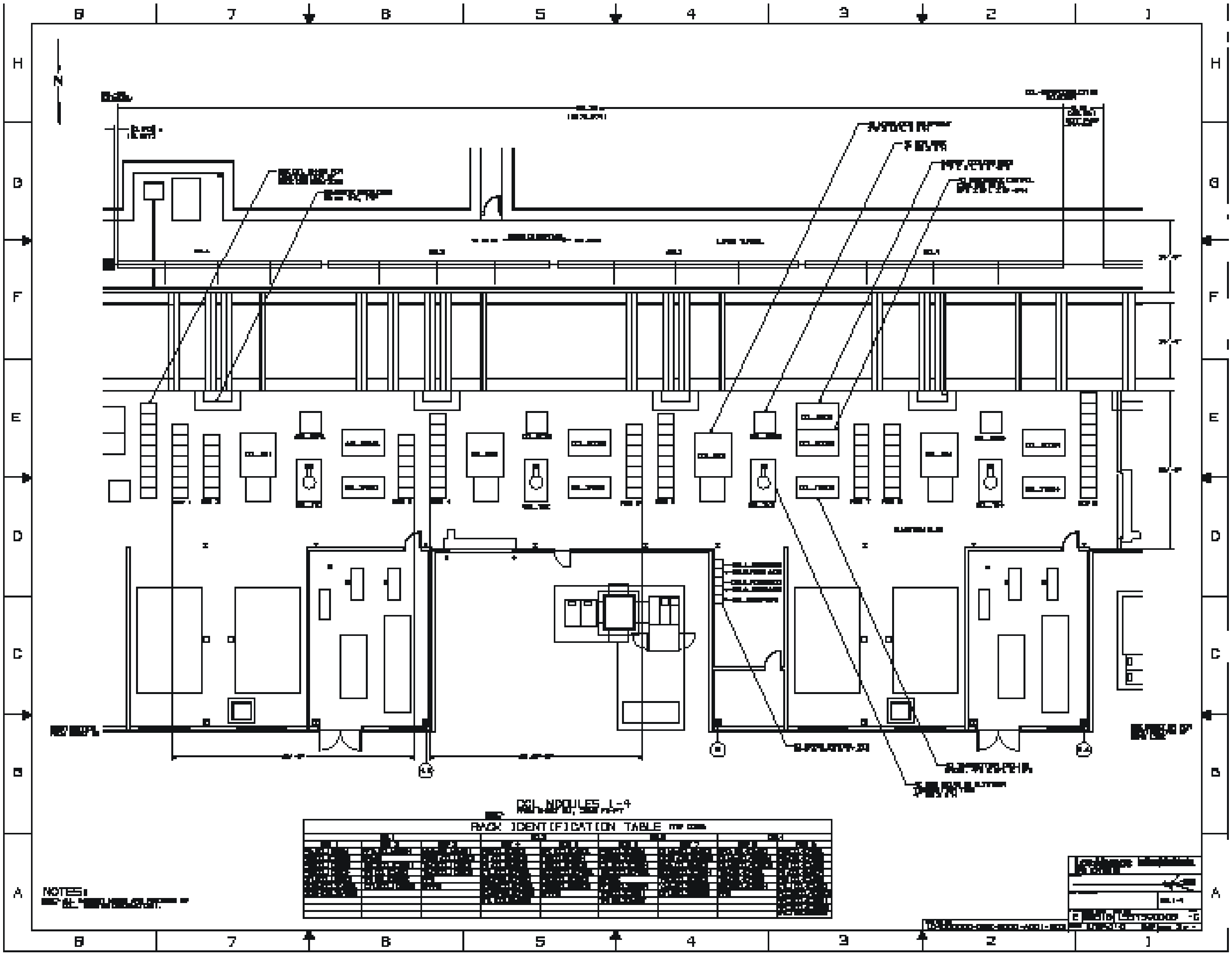


Figure 6.1. SNS Facility plan view in the vicinity of the CCL.

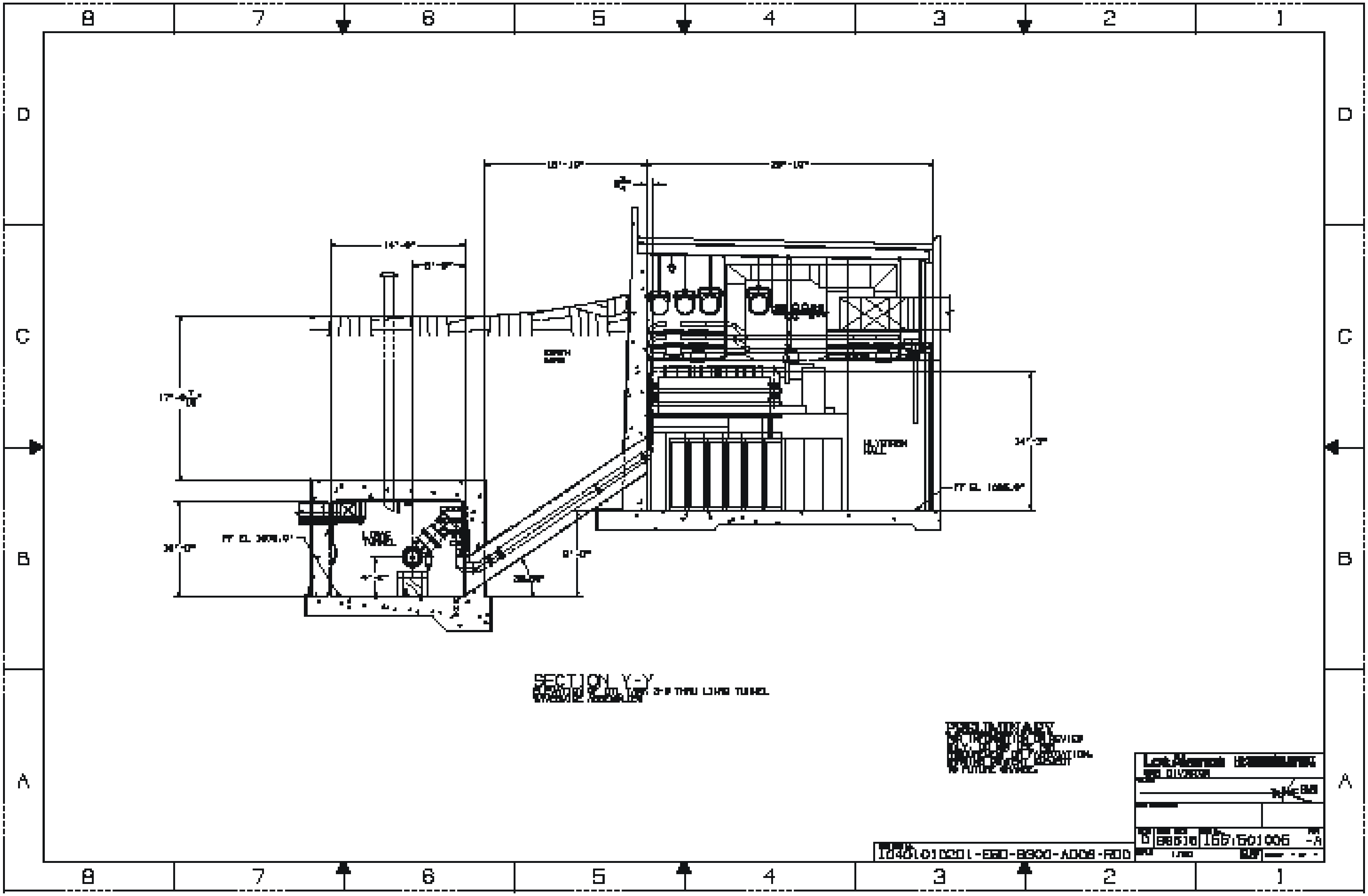


Figure 6.2. SNS Facility cross-section in the vicinity of the CCL.

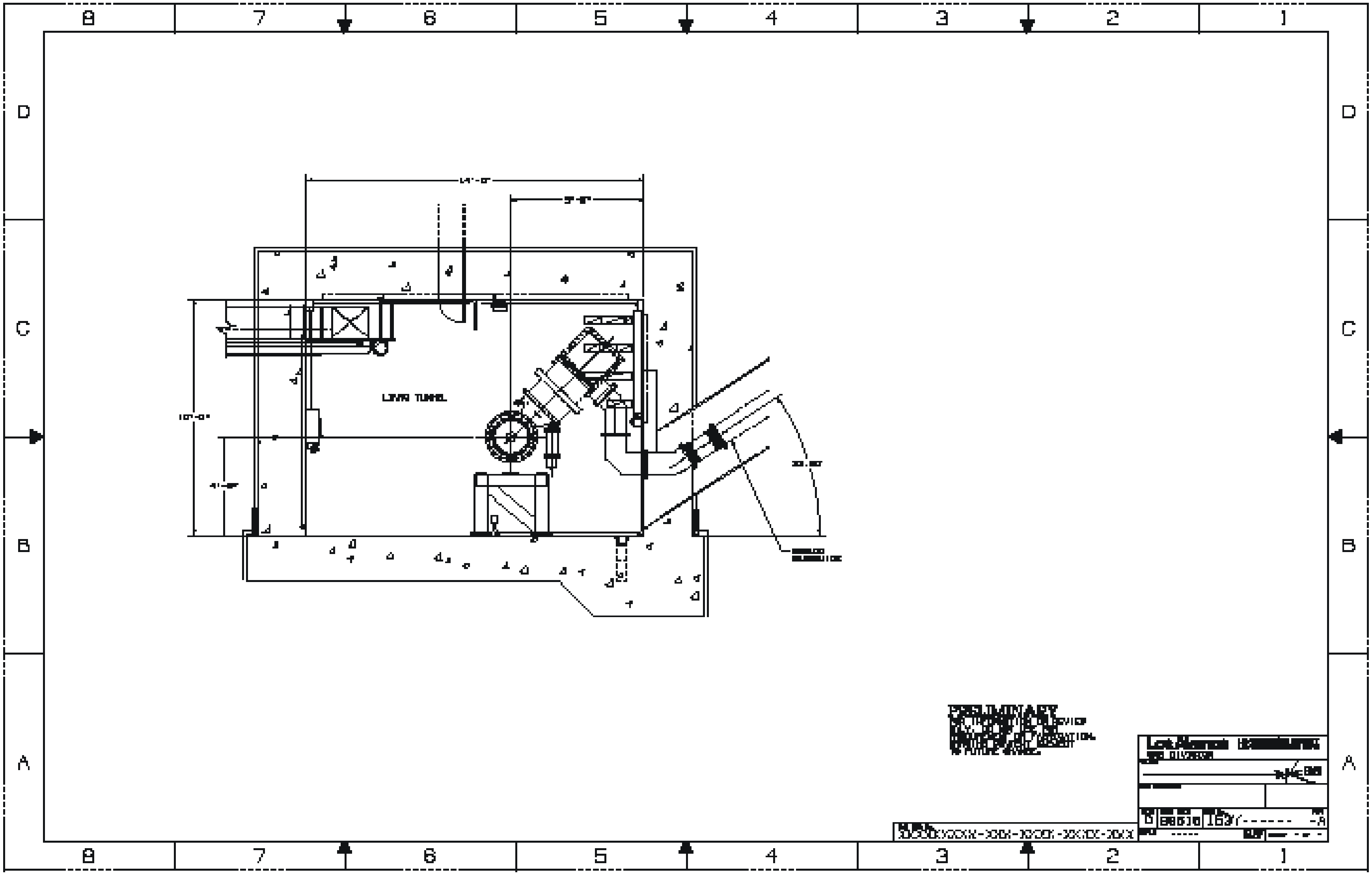


Figure 6.3. Cross-section of the Linac tunnel in the vicinity of the CCL.

through the chases. The chases are centered on each of the CCL modules. The exact routing of the cabling between the chase and the CCL structure is currently under development. It is expected that the vacuum cabling will be routed up to elevated cable trays, where it will run overhead to the associated tank chase entrances, pass through the chases to the Klystron Gallery, and be routed by additional cable trays to the corresponding vacuum controls rack.

RF shielding is required in the Linac tunnel at each chase entrance. The Linac shielding will be similar to the shielding on the Klystron gallery side of the chase. The stacked block shielding will provide a hole large enough for the vacuum cabling lines to pass through and still remain small enough to perform adequate neutron shielding. The shielding requirement on the Linac side of the chase is under design by ORNL.

6.3 Chases

The chases will be located at an angle of 33.5° from the horizontal, running from the Klystron gallery downward to the Linac tunnel. The angled chase will have a length of approximately 20 feet. The chases will serve as passageways for the RF waveguides, water cooling lines, and power/communication cabling. The designs of the chases are currently under development at ORNL.

All vacuum system power and communications cables will be routed between the linac tunnel and klystron gallery via the chases. To simplify the wire routings in the chases and minimize the amount of time required for pulling and routing cables, junction boxes will be utilized on both ends of the chases. The junction boxes will be connected with specified numbers and types of cables, which will be wired and routed prior to installation of the CCL vacuum system. The use of junction boxes will eliminate the need to individually route standard cables and will significantly shorten the required installation time of the vacuum control systems. The installation teams will simply need to wire a vacuum control system electronics rack up to the corresponding junction box in the klystron gallery, as well as wire up the vacuum equipment to the matching junction box in the linac tunnel. Not all vacuum communication cables can be routed through the junction boxes, and will have to be run individually through conduits in the chases. Table 6.1 identifies the types, sizes, and routing plans for the vacuum system cabling on the CCL.

The chases are currently under design and remain the responsibility of ORNL.

Table 6.1 CCL vacuum system power cable requirements in chase conduits.

Module	Power Cable Component	Qty/line diameter	Type	Junction Box Connection?
Each CCL Module (4 total)	• Ion pump power cable	• 10 @ ½” ea	High voltage, low leakage current coax	• No
	• Turbo pump power cables (RF window)	• 2 @ ½” ea	6 conductor, 16 awg, twisted pair	• Yes
	• Scroll pump power cables (RF window)	• 2 @ ¾” ea	3 conductor, 12 awg	• Yes
	• NEG pump power cables	• 2@ 1” ea	3 conductor, 10 awg	• Yes
	• Cold cathode gauge power leads	• 4@ ½” ea	High voltage triax	• No
	• RGA power lead	• 1 @ 1.5” ea	7 conductor, 2 coax cable bundle	• No

7.0 Safety

7.1 Hazard Analyses and Protective Measures

There are numerous safety issues and concerns associated with the design of the CCL vacuum system including mechanical, chemical, electrical, and thermal. This section attempts to itemize the hazards associated with the vacuum system design, and list protective measures that have been incorporated to mitigate them. Additional vacuum design and operational safety information can be found in [7.1].

Some specific potential hazards regarding the CCL vacuum components/operation and their protection measures are discussed below:

1. The NEG pump is constructed with a sintered getter alloy that has pyrophoric properties. While the NEG pump is being activated at temperatures above 100°C, an accidental exposure to atmospheric air may result in combustion. This can be characterized as a very fast oxidation, but is not explosive. Even at temperatures under 100°C, damage to the pumps can occur in various degrees if exposed to atmosphere. By using proper vacuum interlocks and nitrogen gas purging systems, this combustion risk is reduced to an unlikely occurrence.

   Another hazard is the pumping of hydrogen with the pyrophoric NEG material. A NEG pump can sorb several standard liters of hydrogen which can react violently with atmospheric oxygen if the getter material is suddenly exposed to atmosphere. Consequently, it is essential that a NEG pump that has sorbed a substantial amount of hydrogen, undergo a complete regeneration cycle and passivation prior to removal from the vacuum system or exposed to the atmosphere. During regeneration of a NEG, the hydrogen is released from the getter material and removed from the vacuum system by the turbo and scroll backing pumps. The regeneration of a NEG pump takes place in a vacuum that is less that $1x10^{-4}$ Torr. The flow rate at the exhaust of the 70 l/s turbo operating at $1x10^{-4}$ Torr is only $7x10^{-3}$ Torr-Liters/sec. The foreline pressure is generally held below 20 milliTorr by the scroll pump. Under these conditions the hydrogen is given off at such a slow rate and there are not enough oxygen molecules in the vacuum system to form a combustible mixture. It is also unlikely that a combustible mixture could form in the vacuum exhaust. The scroll pump has an automatic ballast that bleeds in air to help flush out particulates and gases. The ballast would in this case further dilute the small amount of hydrogen in the scroll pump exhaust. Again, using proper vacuum interlocks and vacuum operational procedures, the risk of combustion is reduced to an unlikely occurrence.

2. The ion pumps selected for both DTL and CCL vacuum systems require up to 7000 VDC. The ion pump controller can provide up to 100 mA in a short circuit, but the ion pumps are generally operated in the micro-amp range. The high voltage connector is a Fischer Type 105. The ion pump has a retaining screw on the high voltage connector to prevent accidental disconnection of the connector.

   The high voltage connection to the ion pump controller is on the rear of the controller and does not have a retaining screw. However, the ion pump controller will be mounted in an equipment rack that has a lockable rear panel. The ion pump controller has a key switch on the front panel to enable the high voltage. High voltage safety will require proper administrative control of these keys.

3. The turbomolecular pump controller outputs a 56 VAC, 3-phase, 700 Hz signal to the pump. The turbomolecular pump controller can detect an open circuit and will not output a voltage under such a condition. There is also over-current protection that will shut down the output voltage in the event of a short circuit.

4. The scroll pump operates on 208 VAC, 3-phase, 60 Hz and will be controlled by an industry approved motor control circuit with thermal overload protection.

5. Several of the vacuum valves will be electropneumatic and require compressed air up to 125 psi. The 125 psi compressed air system is the responsibility of the ORNL SNS conventional facilities, but its design should be in accordance with all applicable ASME and DOT codes and regulations. The solenoids on the electropneumatic valves will be 24 VDC, which is classified as low voltage.

   The electropneumatic vacuum valves associated with the turbo pumps and beam line will fail closed in the event of an electrical or air line failure, and thus serve to isolate the vacuum. All electropneumatic valves will supply an electrical position signal to the control system.

The control system will prevent the turbo pump valves from being opened, should a proper vacuum not exist on both sides of the valve.

6. Each CCL module will be supplied with a gas pressurization and relief system. The gas purging source will be a standard pressurized gas cylinder containing 99.999% N_2. The gas cylinder will be securely mounted to a portable dolly when in use, and stored in a secure, upright position when not in use. The expanding nitrogen gas cools as it exits the gas cylinder. To prevent freezing damage to the gas regulator, the CCL system should be purged slowly and low temperature regulators, such as made for CO_2, will be used. To prevent over-pressurization of the CCL module, a pressure relief valve with a cracking pressure of 1-2 psig has been included on the tank body. This valve cracking pressure was chosen to be well below the pressurization limit of the CCL module (see Section 4). In the event that the gas pressure regulators on the gas cylinder should fail, a gas flow throttling device was added to ensure that the maximum gas flow into the tank is less than the flow dissipation rate of the relief valve. The gas pressurization lines have been provided with manual valves to vent the system to atmosphere should it be required. Since nitrogen displaces oxygen, the facility will need to determine if a confined space exists near the CCL modules and provide the appropriate controls for such a hazard.

7. The vacuum pressures measured by the high vacuum gauges will be different from the beam line pressure. This difference has been predicted by the computer models in Section 3, and will be incorporated in the control system display and data storage.

8. The beam scattering radiation dose will damage all materials and electronics to various degrees. Only radiation hardened materials will be used for vacuum components (i.e., cables, seals, etc.). All vacuum pump and instrumentation controllers will be located in the electronics rack (klystron gallery), and thus shielded from the accelerator structure's radiation.

9. RF energy can be potentially damaging to vacuum pump and instrumentation housings/components. To prevent significant levels of RF energy from reaching these components, RF attenuation grills, where required, have been placed across pump and instrumentation ports.

10. Electronics racks will have access restrictions (locks) to prevent non-authorized personnel access. The touch screen and computer interfaces with the control systems will be password protected to limit accessibility.

11. All electrical equipment will be UL listed or equivalent and will be installed in compliance with NFPA 70, the National Electrical Code. The relays and solenoids will be of the low voltage 24 VDC type and the wiring will be installed by qualified personnel. Where high voltages are present, there will be protective connectors or shields that will be labeled “High Voltage”.

Table 7.1 summarizes off-normal operating conditions or potential hazards to the vacuum system and corresponding protective measures to monitor and/or mitigate the effects of these conditions. Table 7.1 does not list all possible hazards, however, the ones mentioned were identified from standard engineering practices and applicable engineering codes. For Natural Phenomena hazards such as earthquake, wind, flood and fire, please refer to [7.2].

Table 7.1. Potential Hazards and Incorporated Protective Measures for the DTL/CCL Vacuum System.

System	Sub-System	Fact/Symptom	Protective Measures
Utility		Loss of Power	UPS provided for control system’s PLC and gauge controllers Fail-closed valves employed at pump ports and on beam line. Safe shutdown of all active components
		Loss of Air Supply	Pressure gauges monitored by facility Inline reservoir of sufficient capacity will allow gate valves to close
		Loss of N_2 Supply	N_2 is not used for normal vacuum operations N_2 is used to vent/purge vacuum system - do not vent until N_2 supply is restored
		Loss of Water Supply	Does not affect vacuum
Vacuum Pump	Vacuum Carts	Scroll pump failure	Vacuum gauge monitoring Motor control circuit will provide safe shutdown Automatic isolation valve will close to protect vacuum Oil Free system
		Turbo pump failure	Vacuum gauge monitoring Turbo controller will provide safe shutdown Automatic isolation valve will close to protect vacuum

	Ion Pump	High leakage current	Redundant monitoring (cold cathode gauge)
		Insulation breakdown	Redundant monitoring (cold cathode gauge)
		Pump Failure	Controller will shutdown pump Ion pump failure does not cause immediate shutdown in beam operation
	NEG Pump	H_2 Gas	See Section 7.1
RF	Window	High pressure causing rf breakdown	Vacuum gauge monitoring for RF power shutdown
I&C	General Gauges	Loss of power or gauge failure	UPS for gauge controller Redundant monitoring
	High-Vacuum Gauges	Loss of power or gauge failure	UPS for gauge controller Redundant monitoring
	Valves	Loss of electrical power or gas pressure	Fail-closed valve on turbos and beamline Valve position monitoring
	PLC	Electrical power failure or surge	UPS provided for PLC PLCs are designed for industrial use and are very reliable

7.2 Personnel Safety

In addition to the designed safety features and control safety interlocks mentioned previously in this report, the following personnel safety issues must be considered by ORNL:

- Proper ORNL safe operating procedures and hazard control plans (or similar administrative controls) will be in place at the SNS facility for the assembly, installation, testing, and operation of the vacuum systems.
- All electrical work will be carried out in compliance with ORNL ES&H policies which implement U.S. Department of Energy orders to comply with local, state and federal regulations.
- All vacuum system personnel will receive proper safety training as directed by ORNL personnel guidelines.
- All MSDS related to the vacuum equipment shall be supplied to ORNL by the vacuum hardware vendors.
- Vacuum system components will be subject to radiation activation from beam scattering. Since vacuum system components will have to be serviced, repaired or replaced, workers may be exposed to the induced radiation. The hazard of activation of the vacuum system components must be addressed in a separate Radiation Protection Plan (e.g. safety plans, training, operating procedures, etc.) in accordance with 10 CFR 835, Rev. 1, "Occupational

Radiation Protection". The SNS Facility Manager will need to develop and implement the Radiation Protection Plan.

- ORNL/SNS will be provided with assembly, installation, operations, and maintenance manuals related to the CCL vacuum system, by LANL/SNS.

8.0 Procurement and Fabrication

8.1 Hardware Costs and Procurement Plan

All vacuum components discussed in this final design report, with the exception of the vacuum manifolds, are standard catalog items that do not require any development by a vendor. Table 8.1 lists the required CCL vacuum system components and corresponding cost estimates as obtained from various vendor catalogs and quotes. Spare parts are not included in this estimate. It must be emphasized that listed vendors and hardware costs are for reference only. Similar components by other manufacturers will be considered during a competitive bidding process.

Table 8.1. Summary of CCL vacuum components and unburdened costs.

Item	Vendor	Cat. #	Qty	Unit Cost $	Discount %	Total Cost $
Ion Pump, 300 Liter/sec	Varian	9190405	40	$4,950	25	$148,500
Ion Pump, Controller w/Comp. Int.	Varian	9295000	40	$1,945	25	$58,350
Cable 100 ft	Varian	(N/A)	40	$1,000	25	$30,000
Window Turbo Pump, 70 Liter/sec	Varian	9699360	8	$3,844	25	$23,064
Window Turbo Pump Controller	Varian	9699505	8	$1,508	25	$9,048
Window NEG pump (capacitor)	SAES	B650	8	$4,200	25	$25,200
NEG pump controller	SAES	“	8	$2,200	25	$13,200
Dry scroll backing pump	Varian	SH-100	8	$3,000	25	$18,000
Extension cables 100 ft	Varian/ SAES	(N/A)	24	$1,000	25	$18,000
Turbomolecular Pump Cart	Varian	MSPT9040 MSP0202 MSP90908 MSP0124 MSP0136	2	$19,350	10	$34,830
Pneumatic All-metal Valve, 6 in.	MDC	303006-01-03	8	$2,795	20	$17,888
Manual Inline Valve, 1.5 in.	MDC	302001-01-03	8	$800	20	$5,120
Up-to-Air Valve	MDC	420006	20	$190	20	$3,040
Pneumatic All-metal Gate Valve, 2.5 in.	MDC	303002-01-03	13	$1,620	20	$16,848
Miscellaneous fittings, gaskets & fasteners	N/A	N/A	8	$2,000	20	$12,800
Pressure Relief Valve	Scientific Sales	SSA-PRV-275	8	$270	10	$1,944
Gas throttling device	Alb. Valve & Fitting	N/A	8	300	10	$2,160
Gas bottle & regulators	N/A	N/A	1	$1,000	0	$1,000
Misc. Hoses, fittings, gaskets	MDC	(N/A)	1	$12,000	20%	$9,600
Beamline Flange, 3.375 CCF	MDC	F338000	192	$30	20%	$4,608

Bolt-set, 3.375 CCF per flange	MDC	BA-125/2	192	$5	20%	$768
Bellows, beamline, formed	MDC	FB-6523	48	$60	20%	$2,304
OFHC Seal 3.375 in CCF	MDC	GK-200	192	$2	20	$276
Welding intersegment assembly	(N/A)	(N/A)	48	$200	0	$9,600
Vacuum Manifold w/nipples, 6 in Tube	(N/A)	(N/A)	8	$8,000	0	$64,000
Lot, Misc. Hardware & Gaskets	MDC	(N/A)	8	$1,000	10	$7,200
Bellows w/flanges for Coupling cell (+ machining)	MDC	110022 470016 100022	188	$337	10	$50,685
Blank Flange, 4.625 CFF	MDC	110022	140	$50	20	$5,800
Bolt-set, 4.625 in CCF (25 pk)	MDC	190007	140	$20	20	$2,240
OFHC Seal 4.625 in CCF (10 pk)	MDC	191011	140	$30	20	$3,360
Blank Flange, 2.75 CFF	MDC	F275000	20	$14	20	$224
Bolt-set, 2.75 CCF per flange	MDC	(N/A)	20	$5	20	$80
OFHC Seal 2.75 in CCF	MDC	(N/A)	20	$2	20	$33
Vacuum Manifold Flange, 8” CCF	MDC	110030	80	$100	20	$6,400
Bolt-set, 8” CCF (25 pk)	MDC	190008	80	$25	20	$1,600
OFHC Seal 8” CCF (10 pk)	MDC	190107	8	$48	20	$384
C-cell Pumping Port Flange, 4.625 CCF	MDC	F458300	380	$50	20	$15,200
Bolt-set, 4.625 CCF per flange	MDC	BA-125/2	760	$5	20	$3,040
OFHC Seal 4.625 in CCF	MDC	GL-300	760	$3	20	$1,824
Blank Flange, 4.625 CFF	MDC	F458000	380	$50	20	$15,200
Long Coupling Cell Flange, 8 in	MDC	F800000	176	$100	20	$14,080
Bolt-set, 8 in Flange	MDC	BA-300-PN/2	176	$35	20	$4,928
OFHC Seal in Long CC	Cefilac	(N/A)	176	$30	20	$4,224
Basic Gauge Control Unit	Varian	L8350301	8	$850	10	$6,120
Inverted Magnetron Gauge	Varian	R0310-303	16	$375	10	$5,400
Computer Interface, RS232	Varian	L6439301	8	$150	10	$1,080
IMG circuit board	Varian	L9066301	16	$675	10	$9,720
IMG Cables 100'	Varian	L11733100	16	$355	10	$5,112
Rack Mount	Varian	L6426301	8	$55	10	$396
ConvecTorr circuit board	Varian	L9887301	8	$275	10	$1,980
Six setpoint process control	Varian	L8327301	8	$255	10	$1,836
ConvecTorr Gauge	Varian	L9090302	12	$129	10	$1,393
ConvecTorr Gauge Cable 100'	Varian	L91223100	12	$230	10	$2,484
Residual Gas Analyzer, 1-100 AMU	SRS	TSP2-021120001	4	$8,430	10	$30,348
Equipment Rack, fan, power strip, grounding	APW	N/A	8	$2,000	10	$14,400
PLC (plus cards, input & output connect)	Allen Bradley	N/A	4	$18,000	10	$72,000
Valve interface/indicator box	N/A	N/A	4	$200	0	$800
Local computer	N/A	N/A	1	$3,500	10	$3,150

Software (labview, PLC, etc.)	N/A	N/A	1	$2,000	10	$1,800
					Grand Total	**$824,669**

Detailed performance specifications for major vacuum components have been prepared and are contained in Appendix E. These items will be sent out for bid to DOE/ORNL/LANL specified vendors and purchased by the LANL procurement department. They will be subject to Final/Approved Detail Drawings and LANL-derived selection criteria. Established LANL Quality Assurance Procedures (see Section 8.3) will be followed.

It is speculated at this time that major procurement packages (firm fixed-price contracts) will be developed for the vacuum pumps, instrumentation, and the control system hardware, cables and software. To save costs and effort, these procurements will proceed in parallel with those required for the DTL. Proposed sources will be determined based upon responses to a Commerce Business Daily advertisement or a down-sized list of ORNL pre-approved vacuum equipment vendors.

Vendor selection criteria will include:

- Cost
- Basic fabrication, assembling, and testing capabilities
- Past performance history
- Manufacturing and delivery plan (clear and concise? Risky?)
- Subcontracting plans
- Quality assurance program
- Inspection and testing capabilities
- Ability to meet staggered delivery schedule (see Section 8 of this report)
- On-site survey of contractor facilities

The vendor selection will be competitive and proposals submitted by contractors will be reviewed and judged on cost as well as above mentioned selection criteria. The University of California Technical Representative and Buyer from LANL, or a similar representative from ORNL, will select the lowest responsive and responsible offer from the bids received.

8.2 Delivery and Inspection

All CCL vacuum equipment will be delivered to the SNS Receiving, Acceptance, and Testing (RATS) building at ORNL for inspection and storage prior to assembly. The delivery schedule for this equipment is presented in Section 12. The inspection at the point of delivery will be performed to check for obvious mechanical damage due to shipping problems. Operational or functional inspections will not occur until the vacuum equipment has been assembled to the CCL RF structure. Several months of storage for vacuum hardware may be required prior to assembly and equipment operational checkout. Consequently, the procurement packages will request standard warranties from the time of initial operational checkout, not from the time of delivery.

8.3 Quality Assurance

To ensure the procurement and successful operation of high quality vacuum components, a quality assurance (QA) plan has been developed. The QA plan is comprised of four segments that correspond to the major activities defined in the CCL vacuum system work package; final design, procurement, delivery, assembly/installation/testing.

To initiate the QA plan, this final design report was generated to document the design parameters and requirements, vacuum equipment layouts, engineering calculations, drawings, facility interfaces, control system architecture, procurement/assembly/installation plans, safety features, costs, schedule, etc. This report and its contents will be peer reviewed by an expert committee to certify that the design is compliant with the design parameters and will meet the functional requirements of the SNS.

Upon approval of the final design, detailed procurement specifications or statements of work (SOW) will be generated for each major grouping of vacuum components. These procurement specifications will be included with Request for Proposals (RFPs) which will be sent out to pre-qualified vendors to allow them to submit bids on the various vacuum components. The exceptions to this procurement list are the vacuum system's PLCs, I/O cards, touchscreen interfaces, and electronics racks, which will come from vendors whom SNS has already qualified and established Basic Ordering Agreements with. The various vendor bids will be judged, based upon the acceptance criteria listed in Section 8.1. This will ensure that the SNS project is getting the best value equipment for the purchase price. The QA components of these SOWs will be as follows:

1) QA Program and Procedures: Vendor shall furnish copies of its latest quality assurance inspection and test policies and procedures. In addition, the vendor will be responsible for following University of California (UC) specified vacuum cleaning and handling procedures (see Appendix G). The QA program will be reviewed to determine its adequacy and relevance.

2) Vendor Facilities: To verify production, inspection, testing, and QA/certification capabilities, the vendors will be requested to submit references and provide for on-site visits by UC personnel. Such personnel shall be allowed full access to witness all operations/tests involved in the performance of the SOW. Reasonable advanced notice (24 hrs.) in writing, shall be provided to the vendor prior to any such visits. The UC, at its discretion, may assign and station resident representatives at the vendor's facility to provide program coordination. These representatives will assist in expediting actions between UC and the vendor, maintain program surveillance, and evaluate program progress. The resident representatives shall have access to all areas and information directly related to the scope of their responsibilities specified in the SOW.

3) Qualification and Cerification of Personnel: Vendor's personnel shall have the necessary qualifications and certifications as defined in the SOW to perform the necessary manufacturing, testing, inspection, and certification procedures (i.e., professional engineers, AVS certified vacuum welders, etc.). Qualification and certification records shall be provided by the Vendor.

4) Design Review Prior to Production: For other than off-the-shelf items that must be manufactured, the vendor shall provide a design review as requested by the UC. To facilitate the design review, the vendor shall notify the UC employee of the design review at least 5 working days prior to the review. The notification shall include the proposed agenda, and reproducible paper and electronic copies of each document that constitutes the design or helps to demonstrate that the design meets the UC requirements specified in the SOW.

5) Inspection and Testing Procedures/Reports: Vendor shall prepare and maintain written and detailed inspection and testing procedures that show how the procured items will be verified that they conform to the requirements or specifications in the SOW. These procedures shall be reviewed and approved by the UC. Upon shipment, the vendor shall provide reports of inspections, tests, and certification of conformance. These reports shall be signed by the vendor's authorized personnel and shall be traceable to each shipment. Any deviations from

the SOW technical requirements that are noted in these reports, must be approved by UC prior to shipment.

6) Engineering Drawings: Vendor shall provide all engineering drawings (both in electronic and paper formats) as specified in the SOW.

7) Certifications of Calibration and Conformance: Vendor shall provide with each shipment, when applicable, a certificate of calibration traceable to the shipment and the National Institute of Standards and Technology procedure for calibrating such a device. Vendor shall also provide with each shipment, a "Certificate of Conformance" that is traceable to the shipment stating that the material conforms in all respects with the SOW requirements (i.e., drawings, materials, specifications, inspections, tests, etc.). The certificate shall be signed by the vendor's authorized representative as defined in the vendor's QA program.

8) Failure/Nonconformance Reporting: The vendor shall notify the designated UC employer of each failure or nonconformance against contractually agreed upon engineering, inspection, or test requirements within three working days of the occurrence. Notice shall consist of a written description of the failure or nonconformance, an assessment of the cause, and the proposed corrective action.

9) Corrective Action to Failure/Nonconformance: Following a "notice of failure/nonconformance" from the vendor, the UC will submit a request for corrective action. The vendor shall provide written responses indicating corrective action taken within five working days of receipt of the request for corrective action from the UC.

10) Manuals: The vendor shall submit manuals/instructions that identify storage guidelines, installation procedures, installation testing procedures, special instructions, operating conditions and instructions, preventive and collective maintenance tasks, frequency of tasks, tools and equipment required for installation and maintenance, operating procedures, safety precautions, trouble shooting guides, as well as warranty and contact information. The manuals shall be written in clear, concise language, readily understandable by a technician or craftsman, and it shall conform to the industry standards that prevail for the preparation of such documents.

11) Warranties: For standard off-the-shelf parts, vendors must supply UC with warranties that take effect from the initial time of operation of their products, not from the time of delivery. This will protect the project against buying faulty equipment that is outside a warranty period, simply because it has been in storage prior to operation. The terms of these warranties and the extent of the storage time will need to be agreed upon with the vendors.

The vendors will also be required to submit a complete set of operation manuals upon delivery.

12) Packaging: Items to be shipped shall be packaged according to size, manufacturer, dimensional and manufacturer lot number. Packages of mixed lots, sizes, or products are not acceptable and will be returned to the vendor at vendor's expense. Packages shall be closed and labeled in a manner that identifies the item, dimensions (where applicable), quantity, seller's name and address, manufacturer's name, and shipment address. When required, as specified in the SOW, the packages will be provided with special handling fixtures (i.e., crane and forklift lifting fixtures), have proper insulation against damage, and have shipping insurance.

Upon delivery of the components to ORNL, a visual inspection shall be performed. This inspection will verify the quantity of items delivered including the receipt of required QA documents, MSDS sheets, engineering drawings, and manuals. The inspection will also check for damage due to shipping, and check to see that all dimensional and cleaning requirements have been met. An inspection report shall be generated to indicate the conformance/nonconformance of the shipment. If a nonconformance is indicated, the vendor shall be contacted to perform corrective action to meet the delivery requirements specified in the SOW. Upon successful delivery and inspection of the vacuum hardware, the equipment will be stored in the RATS building until required for assembly.

The vacuum equipment will be assembled on the RF structures and tested for functional and operational compliance. The specific testing and documentation procedures will be specified in the SOW by the UC. A testing report shall be generated to indicate the conformance/nonconformance of the vacuum hardware to the SOW specifications. If a nonconformance is indicated, the vendor shall be contacted to perform corrective action to meet the requirements specified in the SOW. Upon successful testing of the vacuum hardware, a certification document will be completed and signed to indicate the compliance of the vendor supplied material.

While the vendor supplied material may be certified for conformance, the integrated control system, as designed by participating SNS laboratories, will require certification of operation prior to acceptance by the SNS operations team. The testing/certification procedures and documents for this process will be generated following completion of the DTL/CCL Vacuum Systems Final Design Review.

9.0 Assembly, Installation, and Certification Plans

Following fabrication, delivery, and inspection of all CCL vacuum hardware, the assembly tasks for the CCL vacuum system will take place as an integrated effort in the assembly of each CCL module. These assembly tasks will take place in the SNS Receiving, Acceptance, and Testing (RATS) building at ORNL. The anticipated assembly tasks for the CCL vacuum systems are as follows:

- Attach the vacuum manifold mounts to the two CCL half-module support structures.
- Position the vacuum manifold in the mounting apparatus for each half-module.
- Align the vacuum manifold with respect to the RF support structure, using the laser alignment apparatus and the adjustment screws on the manifold mounts. Secure the manifold to the support structure via the mounts.
- Attach the vacuum pumps, valves, vacuum plumbing, and instrumentation to vacuum manifolds as well as the CCL RF window waveguide transition.
- Upon completing the assembly of the CCL RF structures, install the connection bellows between the vacuum manifolds and the side coupling cells and bridge couplers.
- Assemble the CCL vacuum system electronics rack which includes mounting the PLC, vacuum pump and gauge controllers, touch screen, etc., and wiring up the various components to the PLC according to the rack layout and wiring diagrams.
- Connect all vacuum pumps and instrumentation to the control system's electronics rack.
- Connect the pneumatic valves to a pressurized air source and connect the CCL module gas pressurization system.
- Certify operation of all vacuum pumps, valves, and instrumentation.
- Leak check the CCL module halves. Leak checking will be performed according to the procedures and techniques outlined in [9.1].
- Sign-off on the assembly completion certification document to ensure that the assembly process, vacuum equipment check out, and leak check test have been completed per requirements.
- Repeat for the remaining three CCL modules.

To accomplish the CCL vacuum assembly tasks, the RATS building must be equipped with the following:

- Storage space for vacuum components.
- Portable or permanent vacuum shop areas with cleanliness close to class 1000.
- Portable leak detector and helium gas source.
- Nitrogen bottles (99.999% N_2), equipped with coarse and fine gas regulators for purging the vacuum environments.
- Vacuum handling and cleaning procedures and equipment (i.e., cotton gloves, rinse baths, etc.). Cleaning procedures and materials for the CCL are given in Appendix G.
- Standard tools required for assembling vacuum components (i.e., open and box-end wrenches).
- Electrical power and compressed air supplies needed for a complete CCL vacuum system, as specified in Section 1.5.
- Trained and qualified vacuum technicians, capable of cleaning, assembling, inspecting, leak checking, and testing a vacuum system.

The installation of the CCL module and supporting subsystems will take place immediately following certification of the entire CCL assembly and testing process. The installation of the CCL includes transporting the CCL module halves, assorted subsystem components, and control system racks from the RATS building, over to the klystron gallery and linac tunnel. The anticipated installation tasks for the CCL vacuum systems are as follows:

- Remove the main ion pumps and turbo pump cart from the CCL vacuum manifold for transportation to the linac tunnel. Seal the turbo pump cart port with the pneumatic isolation valve and cover the ion pump ports with blank flanges. Pack up the pumps for transportation as well.
- Transport main ion pumps and turbo pump cart to the linac tunnel and attach to the CCL module once it is positioned and mounted.
- Route all pump, gauge, and valve power/communication cables through the waveguide chases or connect to the local junction boxes.
- Connect the gas pressurization source to the pneumatic vacuum valves. Connect all pump, gauge, and valve power/communication cables to the associated pieces of hardware in the linac tunnel.

- Install the CCL vacuum control system electronics rack in the klystron gallery. Connect electrical power lines to the rack. Connect all pump, gauge, and valve power/communication cables to the electronics rack.
- Perform local control system and vacuum equipment operation check-out.
- Connect local control system to the IOC and perform SNS Global Control EPICS interface tests.
- Perform vacuum leak check on the CCL module.
- Sign-off on the installation completion certification document to ensure that the installation process, vacuum equipment check out, and leak check test have been completed per requirements.
- Repeat for the remaining three CCL modules.

At the time of the writing of this document, the final design of the CCL RF structure has not been completed. Consequently, detailed integrated assembly and installation plans have not been written. Upon completion of both the final design of the CCL vacuum system and the CCL RF structure, a CCL Vacuum Assembly, Installation, Testing and Certification Manual will be developed to describe the above tasks and certification procedures in detail.

10.0 Operation, Reliability, and Maintenance

10.1 Operation

During normal operations, the enter CCL vacuum system relies on 40 ion pumps and 8 NEG pumps to provide vacuum. Cold cathode gauges will monitor the vacuum pressures. Each CCL module will have a PLC that will prevent an operating condition that could cause damage or determine if an abnormal conditions exists and use the appropriate interlocks to protect the system. EPICS will constantly monitor the PLC and alert the operator in the case of an abnormal event.

The expected reliability of 80000 hours at 7.5×10^{-7} Torr for the ion pumps resulted in a decision to not use gate valves to isolate the tank from the ion pumps. Without gate valves, the normal operation of the vacuum system is straightforward. Basically, there will be two states; the high voltage to the ion pump is on and the pump current is normal or the pump current or the vacuum pressure is too high, then the pump is shut down.

When the system is pumped down from atmosphere or when the NEG pumps are activated or regenerated, additional interlocks will be in place. These interlocks will prevent an operating condition that could cause damage and protect the system in the event of an abnormal condition.

A complete operations manual will be developed following the completion of the CCL vacuum system final design review.

10.2 Reliability

A measure of the performance in the CCL vacuum system is the ratio of the time that the vacuum system is working satisfactorily, to the time that the beam is shut down due to a vacuum system failure. This performance measure is traditionally made through a reliability, availability, maintainability, and inspectability (RAMI) program. These terms, as they apply to the CCL vacuum system, are defined below [4.4]:

- Reliabiltiy: Probability that the vacuum system will perform as expected for a period of time.
- Availability: The amount of time that the vacuum system is operating as required, divided by the operating time plus down or maintenance time.
- Maintainability: Probability that the vacuum system can be returned or restored to operating conditions when maintenance is performed.

- Inspectability: A measure of the ability to determine if or when maintenance is required to maintain the availability of the vacuum system.

A RAMI program for ensuring a high availability of 85% for the SNS was previously outlined in [4.4]. To meet the 85% availability for SNS, this program required 94.6% to 99.5% availabilities for each of the major SNS subsystems (i.e., from end, Linac, storage ring, conventional facilities, etc.). The SNS Linac was specified as needing to have an availability of 96.1%, which in turn would required even higher availabilities for each of the subsystems (i.e., RF power, LLRF controls, vacuum, water cooling, magnets, diagnostics, etc.). Unfortunately, budget and manpower restrictions eliminated the incorporation of the RAMI plan for the SNS. Consequently, there were no availability or reliability guidelines established for the CCL vacuum systems.

While there are no established reliability requirements for the CCL vacuum systems, good engineering practices were exercised in the design phase to ensure that negative impacts of equipment failure were minimized. First of all, previous particle accelerator vacuum system designs were used as a baseline to develop optimize the design and reliability of the CCL vacuum system [2.5, 2.6, 10.1]. The preliminary CCL vacuum system design was peer reviewed [10.2], as discussed previously in Section 1 of this report. The review committee consisted of accelerator vacuum engineers and technicians from six different National Laboratories. This expert committee related their vacuum design and operation experiences from several accelerator vacuum systems, including SLAC, LANSCE, APS, RHIC, and CEBAF, to strengthen the design and reliability of the SNS CCL vacuum system.

The following design features were incorporated to ensure nearly constant availability of the CCL vacuum systems:

- Ion pumps were chosen for the steady-state operation of the vacuum system. The ion pump specifications (see Appendix E) indicate that the ion pumps will have a mean time between failure of at least 80,000 hours. In the unlikely event that an ion pump fails during beam operation, there is sufficient redundancy in the available pumping speed so that the vacuum system can provide a sufficient vacuum environment until the next scheduled maintenance period.
- A valved turbo pump cart port has been provided in the design of the CCL module. Should two ion pumps fail on a single CCL module, a turbo cart can quickly be installed on the

module to provide extra vacuum pumping and allow the system to continue operating until the next scheduled maintenance period. In the event that a failure occurs on the turbo cart, the electropneumatic valve can be immediately closed to maintain the vacuum environment.

- Tank isolation valves and a nitrogen gasification system were incorporated on each CCL module. Should maintenance be required on the vacuum system, the CCL module can be quickly vented with N_2. Upon completion of the maintenance procedure, a portable turbo cart can be attached to the CCL module and bring it back to operating pressure in less than 15 hours.
- An RGA on each CCL module serves as a redundant pressure measurement and safety interlock should the cold cathode gauge on the CCL vacuum spool piece fail.

10.3 Maintenance

Since both the ion pumps and NEG pumps have no moving parts, they are maintenance free. The cold cathode gauges have no filaments to burn out and do not require any periodic maintenance. The small turbo and scroll pump used to activate and regenerate the NEG will be used only intermittently and only the scroll pump requires servicing. Its minor and major service can easily be scheduled during a planned maintenance period of the linac.

During the planned maintenance period, a visual inspection of the cables is recommended. Cable and feedthroughs are the first items to suspect in an ion pump failure. Although unlikely in the CCL, radiation could affect the integrity of the cables. Inspection of the cables for radiation damage is optional.

If an ion pump fails, there are two options. One is to continue operation of the linac until the next maintenance period if the increased pressure is still within activation limits. The second option is to shut down the linac and vent the CCL to atmospheric pressure with dry N_2 to service the pump. At each end of the tank are isolation valves to preserve the vacuum within the remaining sections of the linac. After servicing and reinstalling the pump, the turbo pump cart will be installed and should be able to pump down the tank rather quickly so that the ion pumps can be re-started as soon as possible

If there is a problem with the turbo pump cart, then the isolation gate valve is closed and the cart removed. The cart can be repaired outside of the linac tunnel at some other time. If the additional pumping from the turbo pump cart is still required, then another cart can be installed. Because of the turbo pump cart isolation gate valve, the vacuum will not be lost and down time will be minimal.

During RF conditioning of the CCL, the turbo pump cart can be operated in conjunction with the ion pumps to help expedite the conditioning. If a failure of the turbo pump cart occurs during this period, then the pump cart will need to be replaced to help overcome the pre-conditioning outgassing rate of the CCL.

Table. 10.1 Summary of Selected Vacuum Pumps

PUMP SYSTEM		ION	TURBO	SCROLL
Model		CapTorr 300	V-300	PTS300
Manufacturer		Physical Electronics	Varian	Varian
Pump Speed				
N_2	L/s	240 (@ 10^{-7} Torr)	280	5
H_2	L/s		210	
Weight	Kg(lb)	70 (149)	8 (17.6)	34 (75)
Reliability Data				
Lifetime	hrs	400,000@ 10^{-7} Torr 80,000@10^{-6} Torr		
MFTF	hrs		80,000	
MFTM	hrs			9000

11.0 Decommissioning

Decommissioning of the SNS will require disconnection and recycling/disposing of the vacuum system components. It is speculated, based on operational experience on the LANSCE accelerator [11.1], that the vacuum pumps, manifolds, and instrumentation, will become radioactively contaminated and will need to be treated as low level radioactive waste. Consequently, disposal of these items will need to follow proper U.S. Department of Energy guidelines for such hardware.

12.0 Project Summary, Ongoing Work, Costs, and Schedule

12.1 Project Summary and Ongoing Work

The design of the CCL vacuum system has been finalized and documented. In particular, the following activities have been completed:

- The vacuum hardware layouts have been completed including the types and sizes of pumps, plumbing, RF grills, and instrumentation. These layouts have been documented in the form of Piping and Instrumentation Diagrams. Specification sheets have been developed for all vacuum hardware in an effort to bring consistency between the CCL vacuum equipment and that from other SNS vacuum subsystems.
- The vacuum analyses for the CCL segment volumes, RF windows, and beam diagnostics have been performed.
- The mechanical designs and analyses for the CCL vacuum system are completed. Material selections and strength issues have been studied and documented. All assembly and detail drawings for the vacuum manifolds, bellows and mounting hardware, have been generated. The vacuum manifold assembly has been incorporated in the top level CCL module #1 assembly.
- The control system architecture has been finalized and is consistent with control layouts from other SNS subsystems (i.e., storage ring vacuum system, linac water cooling systems, etc.). The interfaces between the local control system and global controls have been identified. The control methodology, safety interlocks, and protection equipment facets have been identified. A signal and device spreadsheet for each CCL vacuum system has been generated according to SNS standards.
- A vacuum system hazard analysis has been performed and protective measures to mitigate these hazards have been developed.
- Procurement and fabrication plans have been devised for the CCL vacuum equipment. These plans have been integrated with the DTL vacuum procurements but need to be integrated with the entire SNS vacuum system procurement plans.
- Assembly, installation, and certification plans have been developed to fit within the SNS integrated project schedule.

While the final design of the CCL vacuum system has been completed, there are a number of engineering tasks that are still ongoing or need to be initiated.

- The vacuum manifold assembly drawings need to be incorporated with the top level CCL module assemblies for modules 2 through 4. This will occur when the top level assemblies are available.
- All CCL vacuum system engineering drawings need to be checked, corrected, and signed off. All other CCL hardware drawings that require vacuum system signatures will need to be reviewed.
- A prototype control system, including the PLC, I/O Cards, touchscreen, etc. has been procured. The programming of the PLC ladder logic is under development. This prototype control system will be interfaced with EPICs and tested out on the CCL hot model vacuum system at LANL. This prototype control system will be the model for all of the DTL and CCL vacuum control systems.
- The electronics rack layouts and wiring diagrams for the CCL vacuum systems need to be generated. These will be used by the rack factory at ORNL to assemble the vacuum control systems prior to installation in the klystron gallery.
- The assembly and installation procedures for the CCL modules are still under development. Consequently, the vacuum system assembly and installation plans may need to be adjusted to meet the needs of the CCL.
- Assembly, installation, operation, and maintenance manuals for the CCL vacuum systems need to be generated.
- Procurement specifications for the vacuum pumps, plumbing, and instrumentation need to be finalized with ORNL/SNS. Upon completion of these specifications, Basic Ordering Agreements will be established by ORNL/SNS for all vacuum equipment. Next, vacuum equipment for the DTL and CCL will be ordered and delivered to ORNL.
- Once hardware has been delivered to ORNL, the assembly, installation, and commissioning tasks will be performed.

12.2 Cost Summary

The labor and hardware costs for the design and procurement of the CCL vacuum system are summarized in Tables 12.1 and 12.2, respectively. As Table 12.2 indicates, a cost variance of -$100,000 exists with the vacuum hardware needs of the final CCL vacuum system. A project change request has been drafted and submitted to ORNL for the contingency funding needed to cover the additional hardware expenses.

Table 12.1. Labor cost summaries for the design and procurement activities of the CCL vacuum systems.

Activity	**Total Req'd Man-hours**	**Baseline Costs ($k)**	**Expenditures to Date ($k)**	**Additional Expenditures Expected ($k)**	**Total Expenditures ($k)**	**Overrun (-) or Savings (+)($k)**
Preliminary Design	2284	251.5	251.5	0.0	175.0	0
Final Design	5280	568.9	330.4	160.0	430.4	78.5
Procurement Development	400	23.6	0.0	23.6	23.6	0.0
Documentation	100	0.0	0.0	6.6	6.6	-6.6
Fabrication	320	18.9	0.0	18.9	18.9	0.0

Table 12.2. Burdened hardware procurement cost summaries for the CCL vacuum systems.

Equipment	**Baseline Costs ($k)**	**New Costs base on Final Design ($k)**	**Variance ($k)**	**Reason for Variance**
Vacuum Pumps	325.4	405.4	-80	Unforseen RF window gas loads during RF conditioning necessitates the incorporation of additional vacuum pumps/controllers and instrumentation on the RF window waveguide transition to meet the ambitious Linac commissioning schedule.
Plumbing	193.3	311.8	-118.5	Evolving design of Linac has led to changes in intersegment hardware, support structures, and gaskets/fasteners.
Instrumentation	61.9	77.1	-15.2	The additional instrumentation on the RF window is needed for safety interlocks with the RF power.
Control System	56.8	107.8	-51.0	Design enhancements and assembly/installation requirements call for the use of individual vacuum control systems for each DTL tank and CCL module (rather than a ganged approach). Concurrent assembly/checkout and commissioning activities will require independent module vacuum control systems. An additional prototype control system has been added to allow for development of the control system software and interface hardware with the global control system. Consequently, an increase in hardware cost is required for additional PLCs, electrical hardware, interfaces, etc. Note that the costs of the PLCs were dropped previously from WBS 1.9.4 to allow for incorporation in 1.4.2.4.
TOTAL	637.5	902.1	-264.6	

12.3 Schedule

The project schedule for the procurement, delivery, assembly, and installation of the CCL vacuum systems is shown in Table 12.3. These dates come from a detailed and fully integrated SNS project schedule. In addition, the procurement dates of the CCL vacuum system hardware have been coordinated with similar procurements of the DTL vacuum hardware. Further coordination of the procurement dates may be required if ORNL/SNS would like to combine the DTL/CCL vacuum hardware procurements with those from other SNS subsystems (i.e, front end, super conducting Linac, storage ring, and target area).

The early start and finish dates listed in Table 12.3 are linked to project activities that occur prior in the project time-line. These are the desired dates for which the CCL vacuum system design team will strive for. The late start and end dates represent the latest time that these activities can take place without becoming an SNS project critical path activity.

Further descriptions and details regarding the procurement, assembly and installation tasks can be found in Sections 8 and 9 of this report.

Table 12.3. Schedule for the procurement, delivery, and assembly of the CCL vacuum systems.

Activity	Early Start Date	Early Finish Date	Late Start Date	Late End Date
Documentation & Manuals	23-Jan-01	20-Feb-01	23-Jan-04	20-Feb-04
Control System Programming	23-Jan-01	01-May-01	01-Jul-01	23-Oct-01
Purchase Request to Purchase Order	21-Feb-01	12-Jul-01	23-Oct-02	26-Mar-03
Module 2 Vacuum Fab & Ship	1-Oct-01	5-Dec-01	27-Mar-03	27-May-03
Module 3 Vacuum Fab & Ship	6-Dec-01	14-Jan-02	10-Oct-03	12-Nov-03
Module 4 Vacuum Fab & Ship	15-Jan-02	14-Feb-02	17-Dec-03	26-Jan-04
Module 1 Vacuum Fab & Ship	15-Feb-02	19-Mar-02	27-Feb-04	29-Mar-04
Module 2 Controls/Racks Fab/Ship	1-Oct-01	5-Dec-01	27-Mar-03	27-May-03
Module 3 Controls/Racks Fab/Ship	6-Dec-01	14-Jan-02	10-Oct-03	12-Nov-03
Module 4 Controls/Racks Fab/Ship	15-Jan-02	14-Feb-02	17-Dec-03	26-Jan-04
Module 1 Controls/Racks Fab/Ship	15-Feb-02	19-Mar-02	27-Feb-04	29-Mar-04
Module 2 Vacuum Assembly	6-Mar-02	26-Jun-02	28-May-03	19-Sep-03
Module 3 Vacuum Assembly	27-Jun-02	28-Aug-02	13-Nov-03	26-Jan-04
Module 4 Vacuum Assembly	29-Aug-02	31-Oct-02	27-Jan-04	29-Mar-04
Module 1 Vacuum Assembly	20-Nov-02	31-Jan-03	30-Mar-04	28-May-04
Module 2 Vacuum Installation	14-Jan-03	12-Mar-03	11-May-04	7-Jul-04
Module 3 Vacuum Installation	13-Mar-03	9-Apr-03	8-Jul-04	4-Aug-04
Module 4 Vacuum Installation	10-Apr-03	7-May-03	5-Aug-04	1-Sep-04
Module 1 Vacuum Installation	2-Sep-04	29-Oct-04	2-Sep-04	29-Oct-04

13.0 Appendix A – SLAC B-Factory Vacuum Outgassing Summary

MEMORANDUM

Memo Number: **PPO-MEM-01948**

To: **Martin Schulze**

From: Alex. Harvey

Date: March 10th, 1999

SUBJECT: CONTRACT NO. DE-AC04-96AL89607;
OUTGASSING RATES FOR CU & S.S.

Here are the values and sources of the outgassing rates I would propose using for copper (CCDTL cavities), and stainless steel (expander chamber and beam-line):

Copper (OFE, machined, and subjected to hydrogen brazing):

Initial rate (for pump-down): 1.0E-9 T-l/s-cm^2
(SLAC, "Stanford 2-mile Accelerator")

Residual rate (operating): 1.0E-11 T-l/s-cm^2
(same, and Dan Wright, SLAC engineer)

Stainless Steel (degreased, not baked):

Initial rate: 1.0E-9 T-l/s-cm^2
(Varian "Review of Outgassing Results" VR-51, 1968)

Residual rate: 1.0E-10 T-l/s-cm^2
(same)

Stainless Steel (baked @ 400C for 24 hr)

Residual rate: 1.0E-12 T-l/s-cm^2
(both Varian and SLAC)

There is clearly some advantage in baking S.S., if we can do it.

Cc: George Spalek
Rick Wood
Peter Dumitriu
Chelly Weiss

14.0 Appendix B – RGA Analysis of the APT/LEDA CCDTL & LANSCE CCL

Applied Research Engineering Division
Accelerator Technologies Engineering Group

LLNL-ATEG-99-201
December 16, 1999

RGA Analysis of the APT CCDTL Low-Beta Hot Model
For use as a Baseline for the
Spallation Neutron Source Linac Vacuum System Design

K. Kishiyama, Electrical Engineer, ATEG/LLNL

Introduction

The proposed SNS Cavity Coupled Linac (CCL) will utilize fabrication techniques similar to the existing APT CCDTL Low-Beta Hot Model (LBHM). The LBHM is a hydrogen brazed OFE copper structure and the data obtained from the LBHM vacuum system should be helpful in the design of the SNS CCL vacuum system.

The scope of this discussion will be limited to the LBHM data provided by Paul Leslie from LANSCE-1. The relative percentage of the main residual gases will be calculated from the RGA spectrums obtained from the Leybold-Inficion Transpector installed on the LBHM. The LBHM has been under vacuum for several months and has been operated with high power RF. This discussion will focus on what might be the expected composition of SNS CCL vacuum after a few thousand hours under vacuum and high power RF conditioning based on the observations from the LBHM.

Analysis

The Leybold-Inficion Transpector RGA provides partial pressure data in the form of ion intensity versus the ion mass to charge ratio. The ion intensity is measured in amperes. A spectrum from the LBHM taken 7/29/99 is shown in Figure 1. A rough estimate to convert ion current to partial pressure (Torr) can be made using published sensitivities, ionization probabilities, fragmentation factors and ion transmission factors. However, all of these factors are dependent on the individual instrument due to variations in electron energy, mass tuning, ionizer design, etc. To accurately convert ion current to partial pressure requires careful calibration with accurate test equipment [1]. Actually calibrating the RGA would be beyond the scope of this discussion and therefore only an estimate of the partial pressures will be made here based on published values for sensitivities, ionization probabilities, fragmentation factors and ion transmission factors. [2].

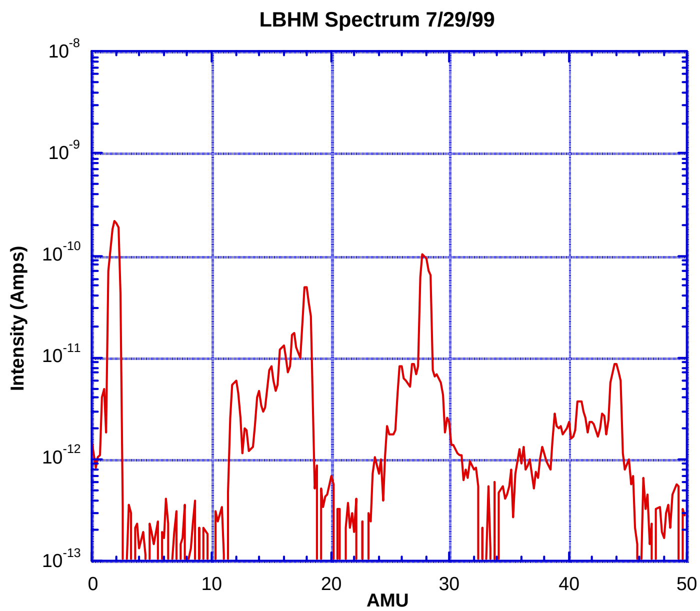


Figure 1. LBHM spectrum from 0 to 50 AMU

The Leybold-Inficon Transpector User Manual provides the following general equation for the conversion of ion current to partial pressure in units of Torr:

$PP_a = \{FF_{28} / (FF_{ab} * XF_a * TF_a * DF_a * G * S)\} * I_{ab}$

Where:

PP_a = partial pressure of substance a in Torr

FF_{28} = fragmentation factor for Nitrogen (typically = 0.94)

FF_{ab} = fragmentation factor of substance a having mass b

XF_a = ionization probability

TF_a = transmission factor, the fraction of ions at mass b which pass through the mass filter relative to ions at mass 28, $TF_a = 28/a$

DF_a = detection factor for mass b from substance a relative to mass 28, assumed to be 1.00 for Faraday detectors, but must be calibrated for electron multipliers

G = gain of electron multiplier for mass 28, must be calibrated

S = sensitivity of instrument for mass 28 in amps/Torr

I_{ab} = ion current of mass peak b from substance a in amps

The ion currents from the spectrum shown in Figure 1 were used to calculate the partial pressures of the five main gas species typically found in a vacuum system. Table 1 summarizes the calculations. Note that the percentages do not add up to 100%. There are several other gas species present whose partial pressures were not calculated.

Table 1. Calculated percentages in LBHM.

RGA Spectrum Analysis of APT/LEDA CCDTL Hot Model		
Gas species	**AMU**	**Percent concentration**
Hydrogen	2	18%
Methane	16	3%
Water vapor	18	20%
Nitrogen/Carbon Monoxide	28	49%
Carbon Dioxide	44	7%

The relative percentages generally agree with published values for OFE copper [3], [4], but there will always be variations in the exact composition of the vacuum due such factors as manufacturing processes, cleaning processes and surface finishing. Note that since hydrogen is not as soluble in copper as compared to stainless steel, it is generally not the predominate gas in a copper vacuum system while it usually is in a stainless steel vacuum system.

In examining the raw spectrum in Figure 1, it initially appears that hydrogen is the dominant gas species, but the analysis in Table 1 shows mass 28, nitrogen/carbon monoxide, constitutes the largest percentage of residual gases in the vacuum. The reason why the raw spectrum shows hydrogen as the largest peak is because the ion transmission factor is greater for smaller masses. To scale the data for the transmission factor to mass 28, the ratio of the two masses is used. For hydrogen, the ratio of mass 28 to mass 2 is 14. By taking into account the ion transmission factor, the ionization probability and the fragmentation factor, the hydrogen peak must be scaled down by a factor of 6.16 before the conversion of ion intensity to pressure.

Using data from the stabil-ion gauges on the LBHM, the base pressure reached 1.6×10^{-8} Torr in August 1999. The LBHM had been under vacuum since the middle of January 1999. The system was only bought up to atmosphere a few times and each time it was with a nitrogen purge. By the end of July the LBHM had approximately 60 hours of RF operation. By the end of July, approximate power levels were 15 kW. The effective pump speed of the four ion pumps being used on the LBHM was calculated to be 48 liters/sec. This calculation was based on the pump speed measurements performed in January 1999 [5] on the LBHM using four ion pumps and two turbo pumps. The approximate surface area of the LBHM is 12,000 cm^2. The outgassing rate for the LBHM was calculated to be 6.4×10^{-11} Torr-liters/sec/cm^2.

At the end of September 1999, RF power was approaching 40 kW and the base pressure of the vacuum system reached 5.0×10^{-9} Torr. Using the same pump speed and surfaces areas as above, the outgassing rate is calculated to be 2.0×10^{-11} Torr-liters/sec/cm^2. These values are within the range of values found in published data [6].

Finally, the spectrum from 0 to 100 AMU taken on June 23, 1999 shown in Figure 2 has significant hydrocarbon contamination. The hydrocarbons appear to be volatile and with the help of the RF conditioning, have generally been pumped out of the system. Peaks 39 and 41 for example are an order of magnitude less in amplitude in the spectrum taken on July 29, 1999 shown in figure 1.

The purpose of noting the hydrocarbon contamination in the LBHM is to bring to attention the need for ultrahigh vacuum handling practices for achieving the target vacuum pressures in the SNS CCL module 30 vacuum system. While the LBHM finally reached a very good outgassing rate, it required several thousand hours under vacuum and many kilowatts of RF conditioning. It is cost and time effective to design ultrahigh vacuum handling practices into the manufacturing and installation of the cavities.

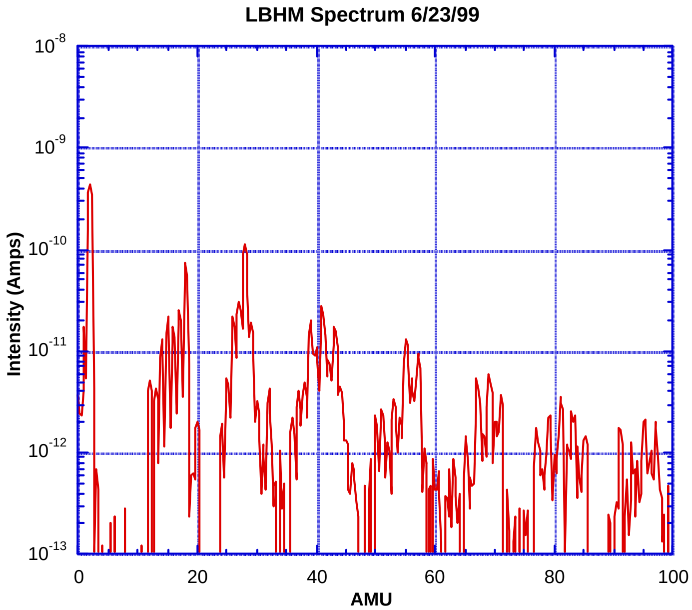


Figure 2. LBHM spectrum showing hydrocarbon contamination

[1] J. Basford *et al*., *American Vacuum Society Recommended Practice for Calibration of Mass Spectrometers for Partial Pressure Analysis*, J. Vac. Sci. Technol. A 11(3) 22 (1993)

[2] R. L. Summers, *Empirical Observations on the Sensitivity of Hot Cathode Ionization Type Vacuum Gauges*, NASA Technical Note TN D5285, (1969)

[3] S. Dushman, *Scientific Foundations of Vacuum Technique*, 2nd Edn, Wiley, New York (1962)

[4] G. F. Weston, *Materials for Ultrahigh Vacuum*, Vacuum, 25(11/12) 469 (1975)

[5] K. Kishiyama *et al*., *Test Report: Accelerator Production of Tritium/Low Energy Demonstration Accelerator CCDTL Phase 3A Low Beta Hot Model Pump Speed Tests*, LLNL-ATEG-99-203, April 13, 1999

[6] J. O'Hanlon, *A User's Guide to Vacuum Technology*, Wiley, New York, (1980)

Residual Gas Analysis of LANCE LINAC module six

By: Cort Gautier LANL

The LANCE LINAC is one of only a few pulsed proton LINAC's operating in the world. Vacuum data obtained from the LANCE LINAC should be useful for the design of the SNS linac
A RGA spectrum of the LANCE side coupled linac module 6 has been analysed.
The spectrum was taken with a Stanford Research Systems (SRS) RGA 200.

The sum of the individual partial pressures gives a total system pressure of 5.87×10^{-7} Torr.

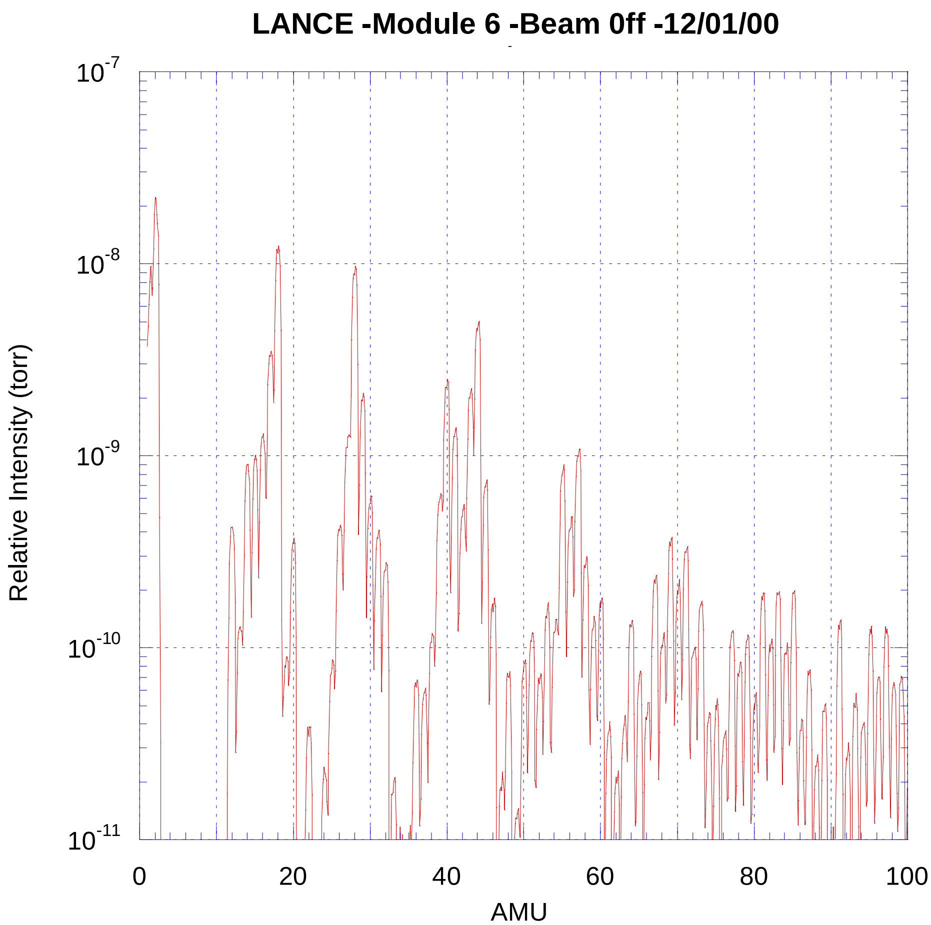
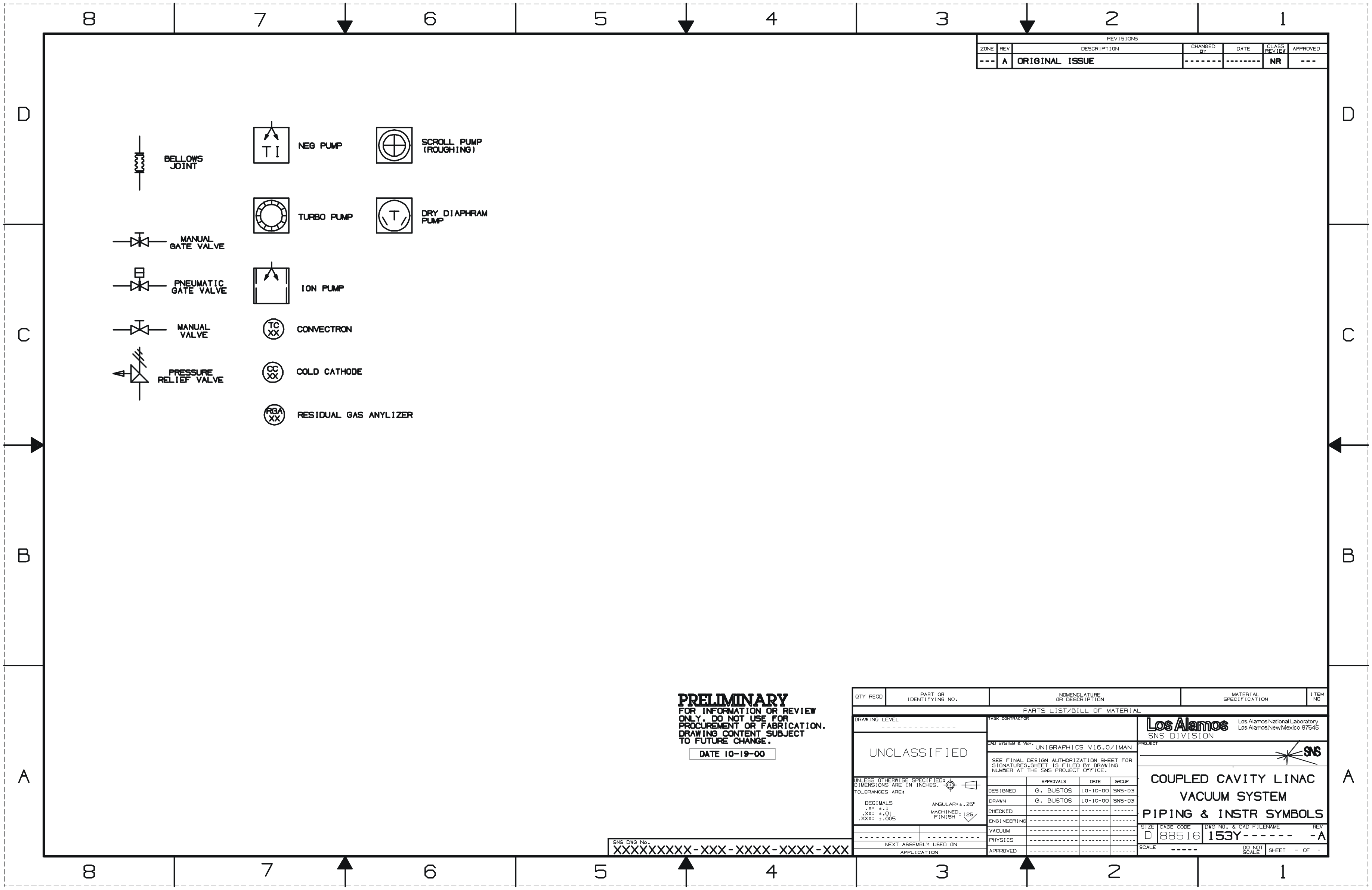


Figure B.1. RGA scan of CCL module 6 on the LANSCE Linac.

15.0 Appendix C – Engineering Drawings



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SCROLL PUMP (ROUGHING)
TURBO PUMP
DRY DIAPHRAM PUMP
MANUAL GATE VALVE
PNEUMATIC GATE VALVE
ION PUMP
MANUAL VALVE
TC XX
CONVECTRON
PRESSURE RELIEF VALVE
CC XX
COLD CATHODE
RGA XX
RESIDUAL GAS ANYLIZER
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DRAWN | G. BUSTOS | 10-10-00 | SNS-03
CHECKED
ENGINEERING
VACUUM
PHYSICS
APPROVED
Los Alamos
SNS DIVISION
Los Alamos National Laboratory
Los Alamos,New Mexico 87545
PROJECT
SNS
COUPLED CAVITY LINAC
VACUUM SYSTEM
PIPING & INSTR SYMBOLS
SIZE D
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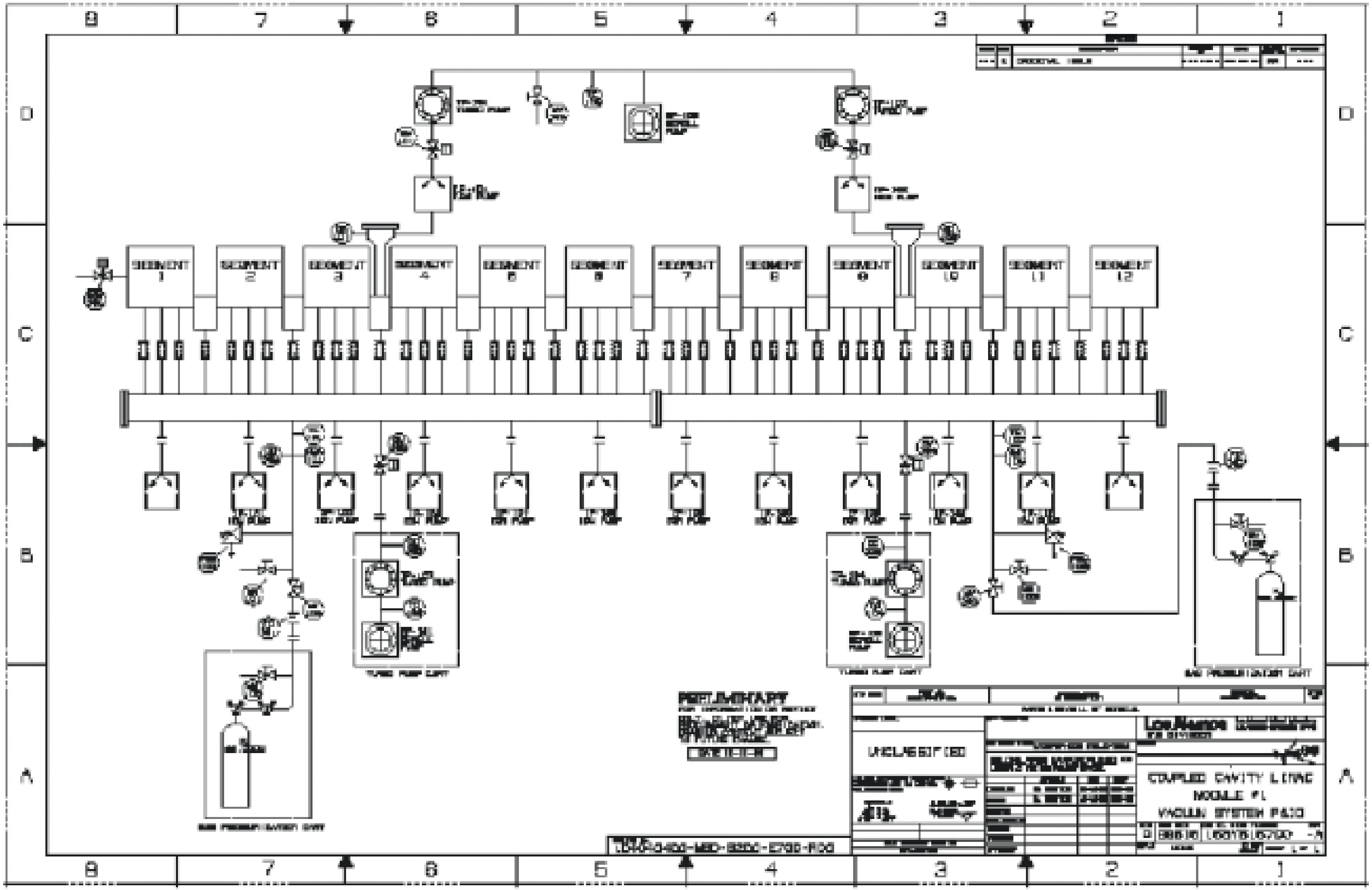

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Los Alamos
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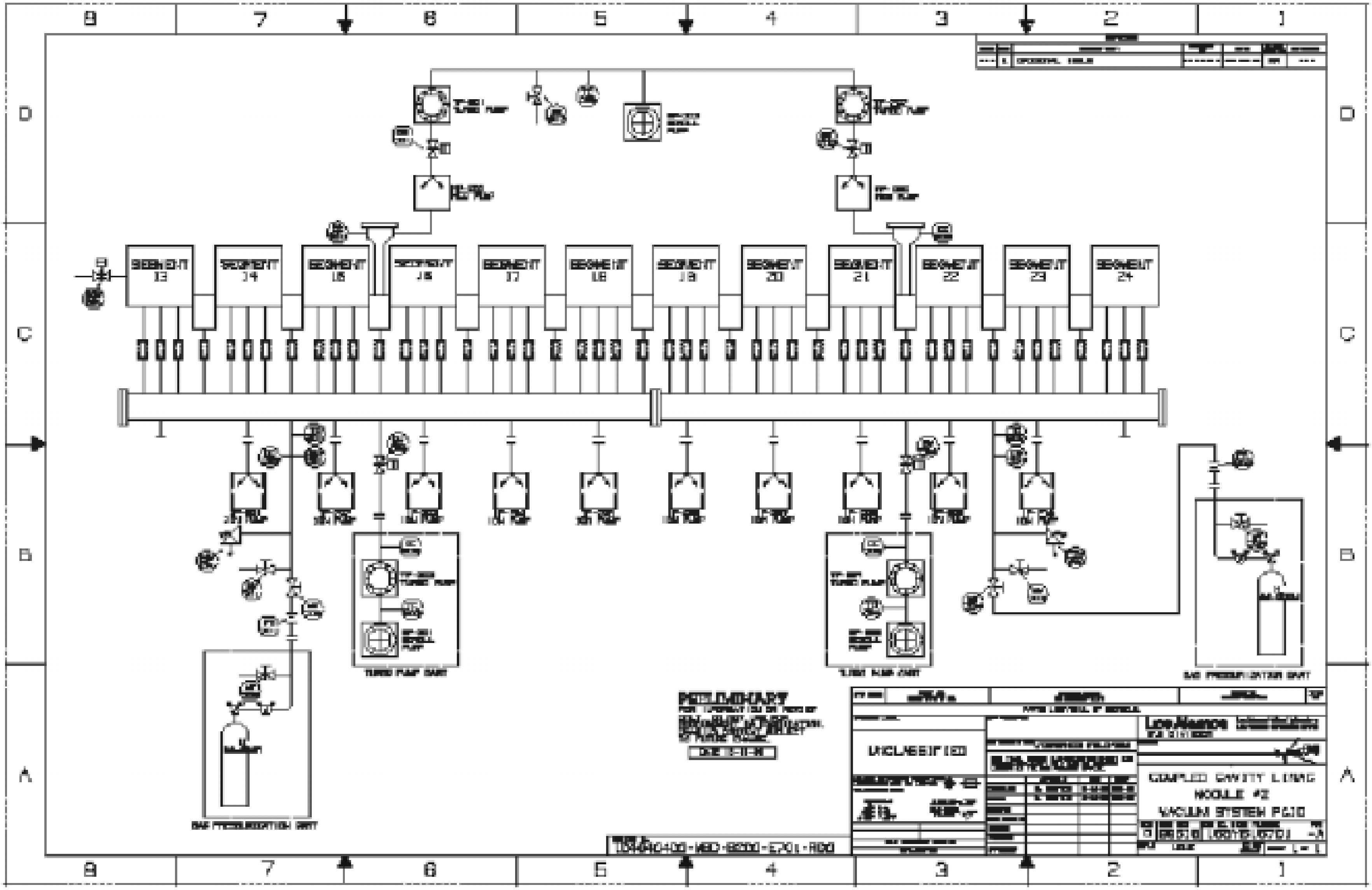

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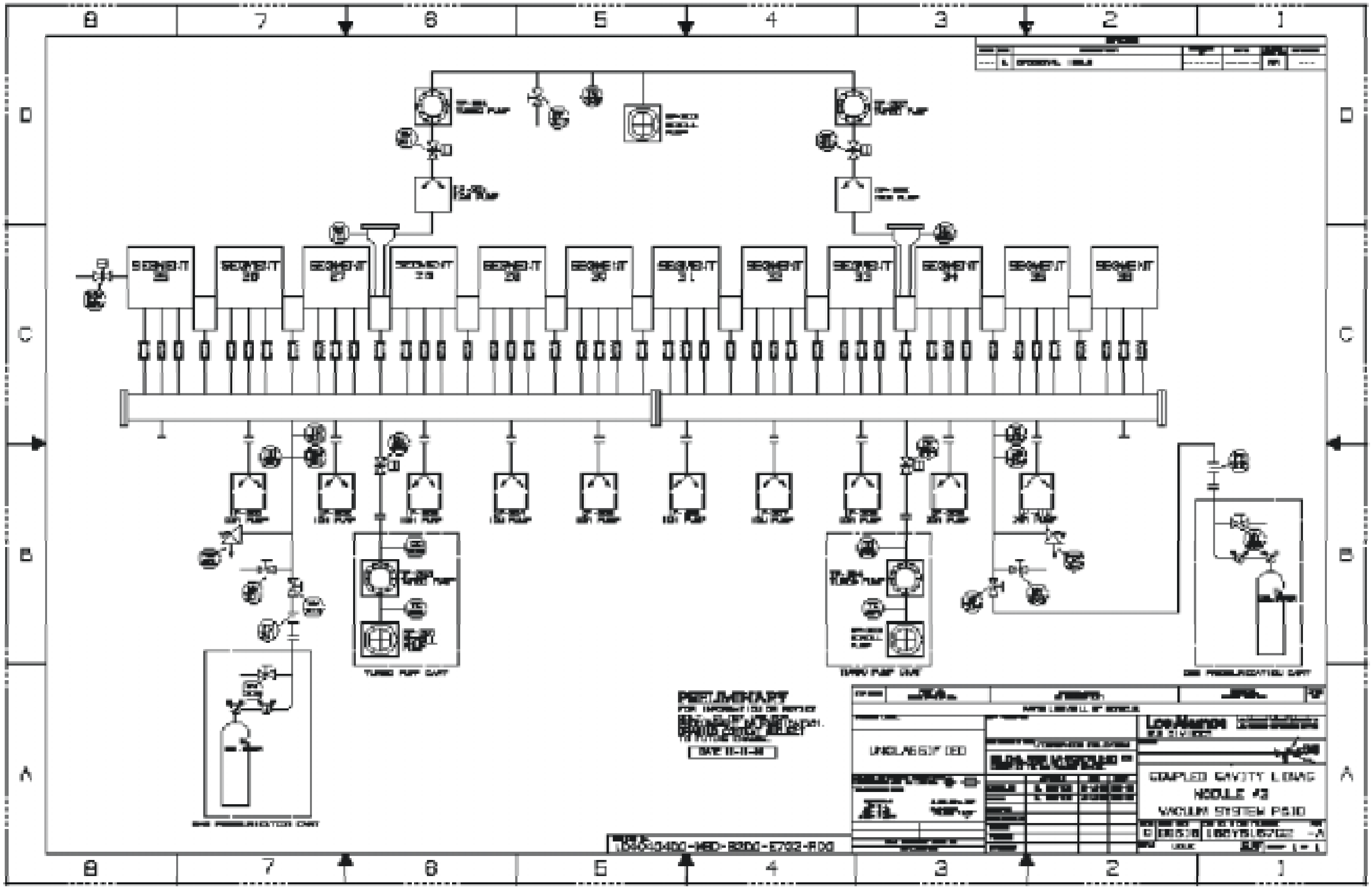

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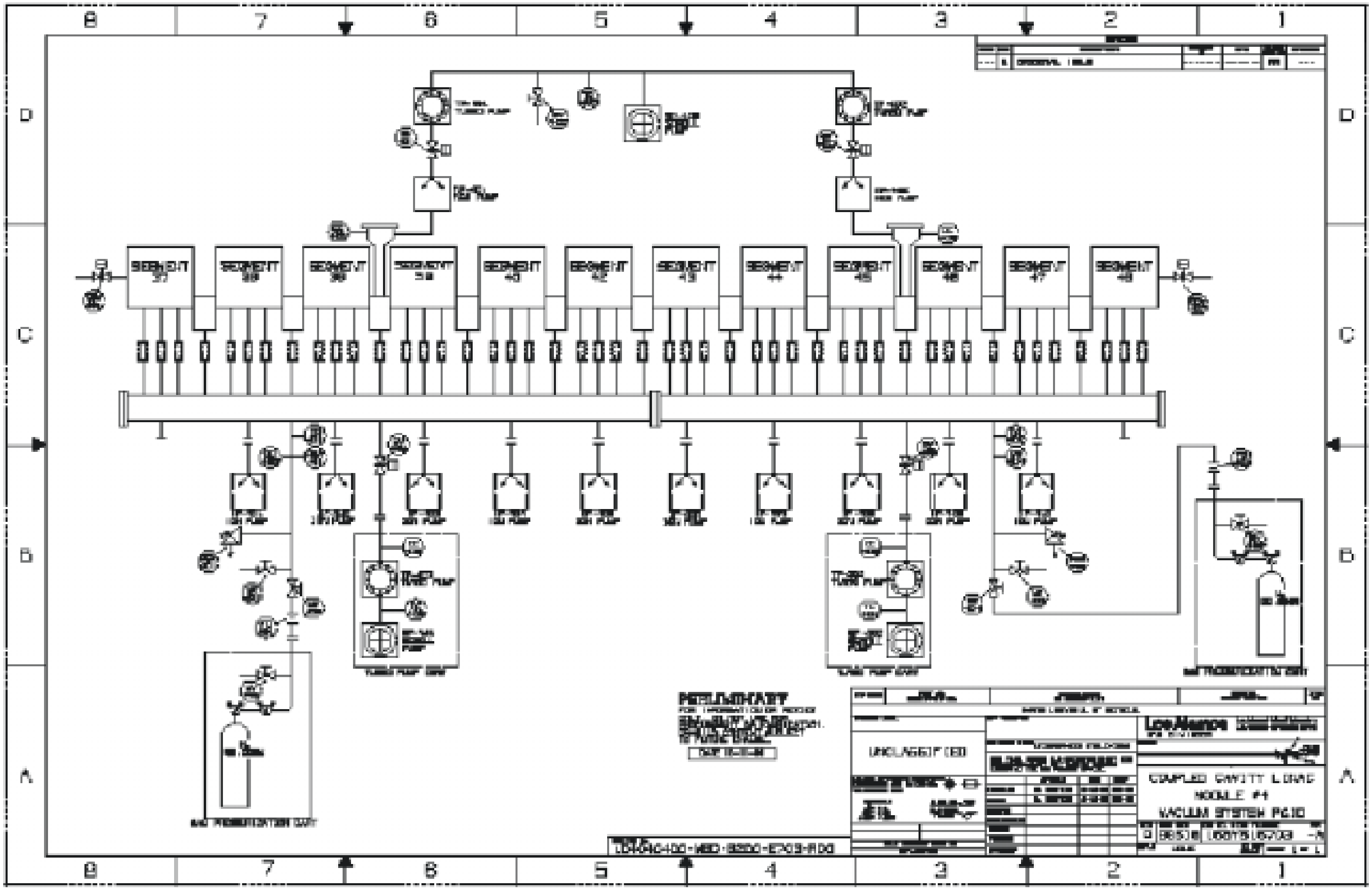
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DRIFT TUBE LINAC "DTL" STRUCTURE MAGNET,DIAGNOSTIC LAYOUT

SYMBOL IDENTIFICATION	DIAGNOSTIC NAMING	QUANITY
QV	PERMANENT MAGNET QUAGRUPOLE VERTICAL	74
QH	PERMANENT MAGNET QUAGRUPOLE HORIZONTAL	73
QT	QUADRUPOLE TRIM	11
DH	ELECTRO MAGNET DIPOLE HORIZONTAL	15
DV	ELECTRO MAGNET DIPOLE VERTICAL	16
	BEAM POSITION MONITOR	10
	CURRENT MONITOR	6
	FAIRADAY CUP	5
	ENERGY DEGRADER	5
	WIRE SCANNER	5
	GATE VALVE	5
	HARP	2
	BEAM LOSS MONITOR	6
	VIEW SCREEN	1

COUPLED CAVITY LINAC "CCL" STRUCTURE MAGNET,DIAGNOSTIC LAYOUT

SYMBOL IDENTIFICATION	DIAGNOSTIC NAMING	QUANITY
	QUADRUPOL MAGNET	48
	BEAM POSITION MONITOR	15
	CURRENT MONITOR	1
	BEAM LOSS MONITOR	48
	WIRE SCANNER	7
	FARADAY CUP	1
	GATE VALVE	3
	ENERGY DEGRADER	1

CCL/SCL TRANSITION AREA STRUCTURE MAGNET,DIAGMOSTIC LAYOUT

SYMBOL IDENTIFICATION	DIAGNOSTIC NAMING	QUANITY
	QUADRUPOL MAGNET	2
	BEAM POSITION MONITOR	2
	CURRENT MONITOR	1
	BEAM LOSS MONITOR	1
	WIRE SCANNER	1
	PRECIPITATOR	1
	FARADAY CUP	1
	GATE VALVE	2
	ENERGY DEGRADER	1

SUPER CONDUCTING LINAC "SCL" STRUCTURE MAGNET,DIAGNOSTIC LAYOUT

SYMBOL IDENTIFICATION	DIAGNOSTIC NAMING	QUANITY

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ANGULAR: ±.25°
MACHINED FINISH = 125

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DIAGNOSTICS	------------	--------	------
WATER	------------	--------	------
PHYSICS	------------	--------	------
MAGNETS	------------	--------	------
DTL ENG	------------	--------	------
CCL ENG	------------	--------	------
VACUUM	------------	--------	------
APPROVED	------------	--------	------

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Los Alamos National Laboratory
Los Alamos,New Mexico 87545

PROJECT
SNS

SNS
LINAC DIAGNOSTIC LAYOUT
QUADRUPOLE MAGNET LAYOUT

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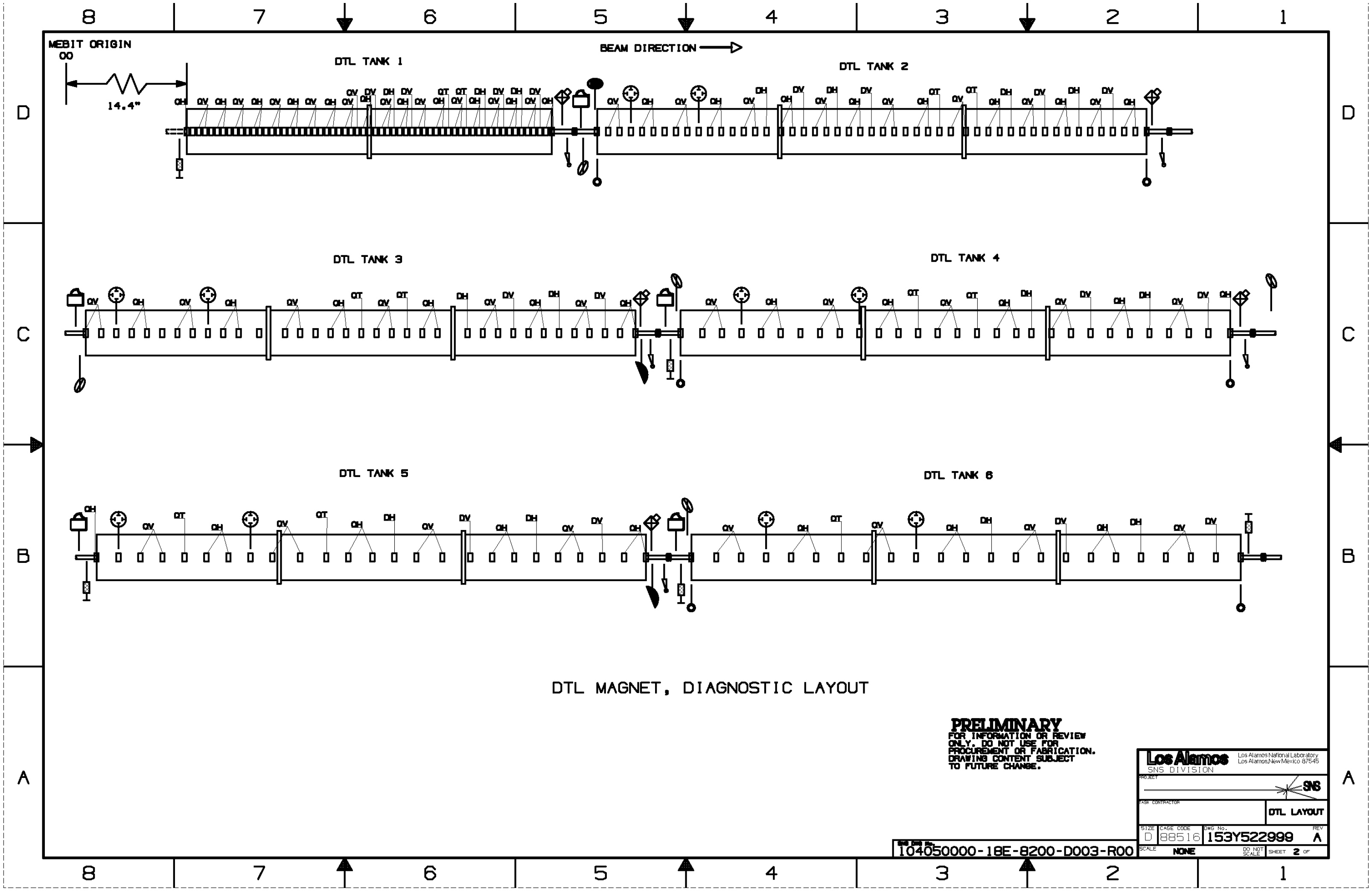
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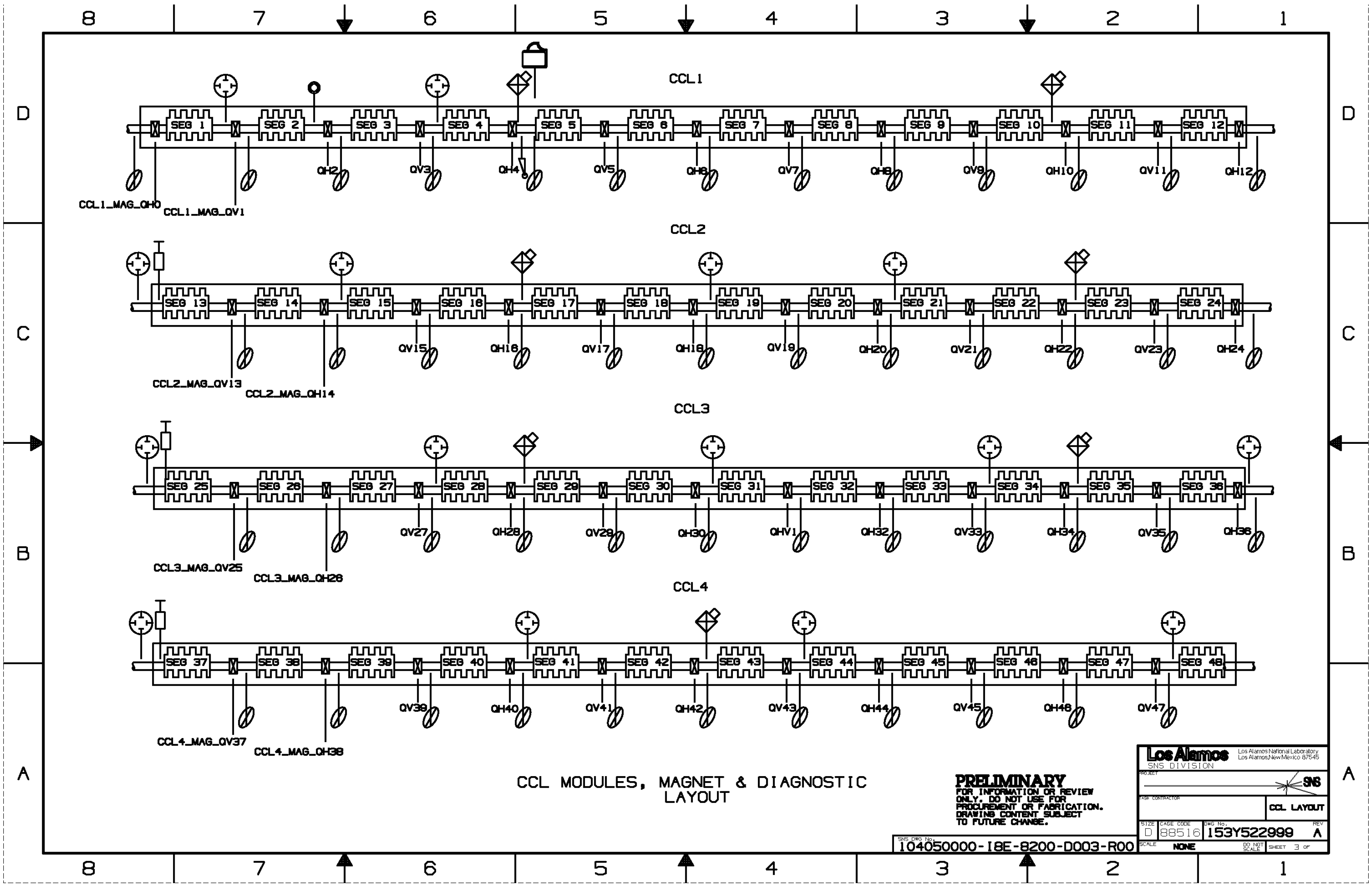
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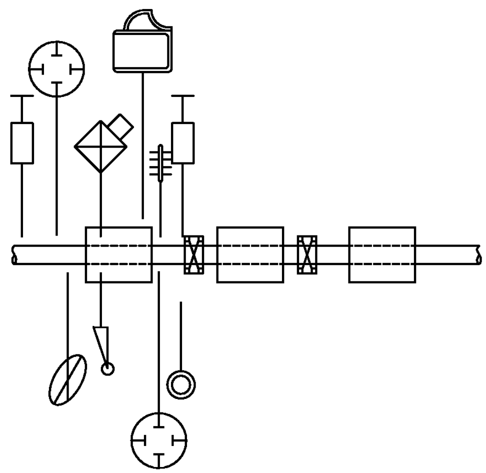

CCL/SCL TRANSITION AREA

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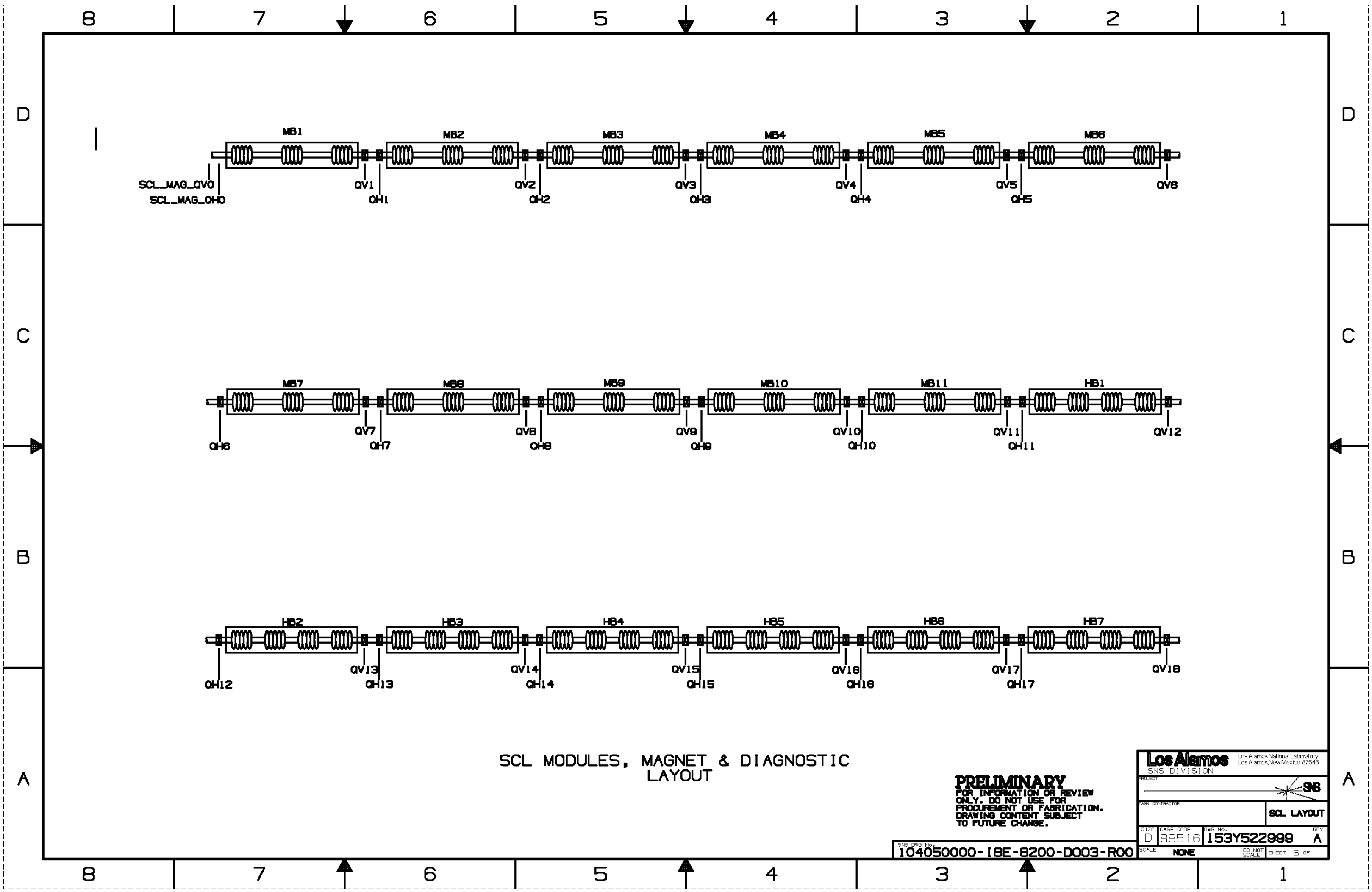

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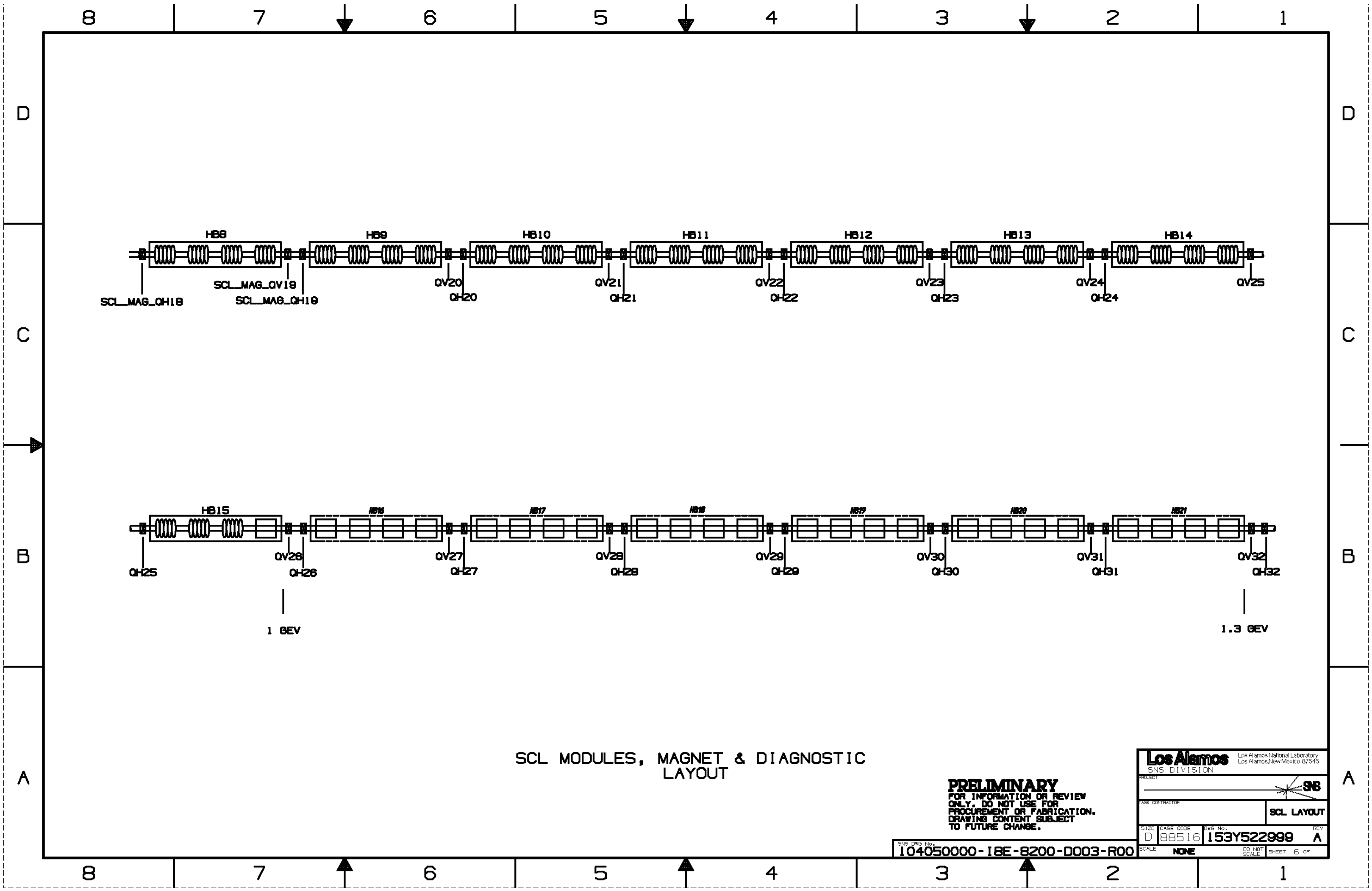

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1.3 GEV
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LAYOUT
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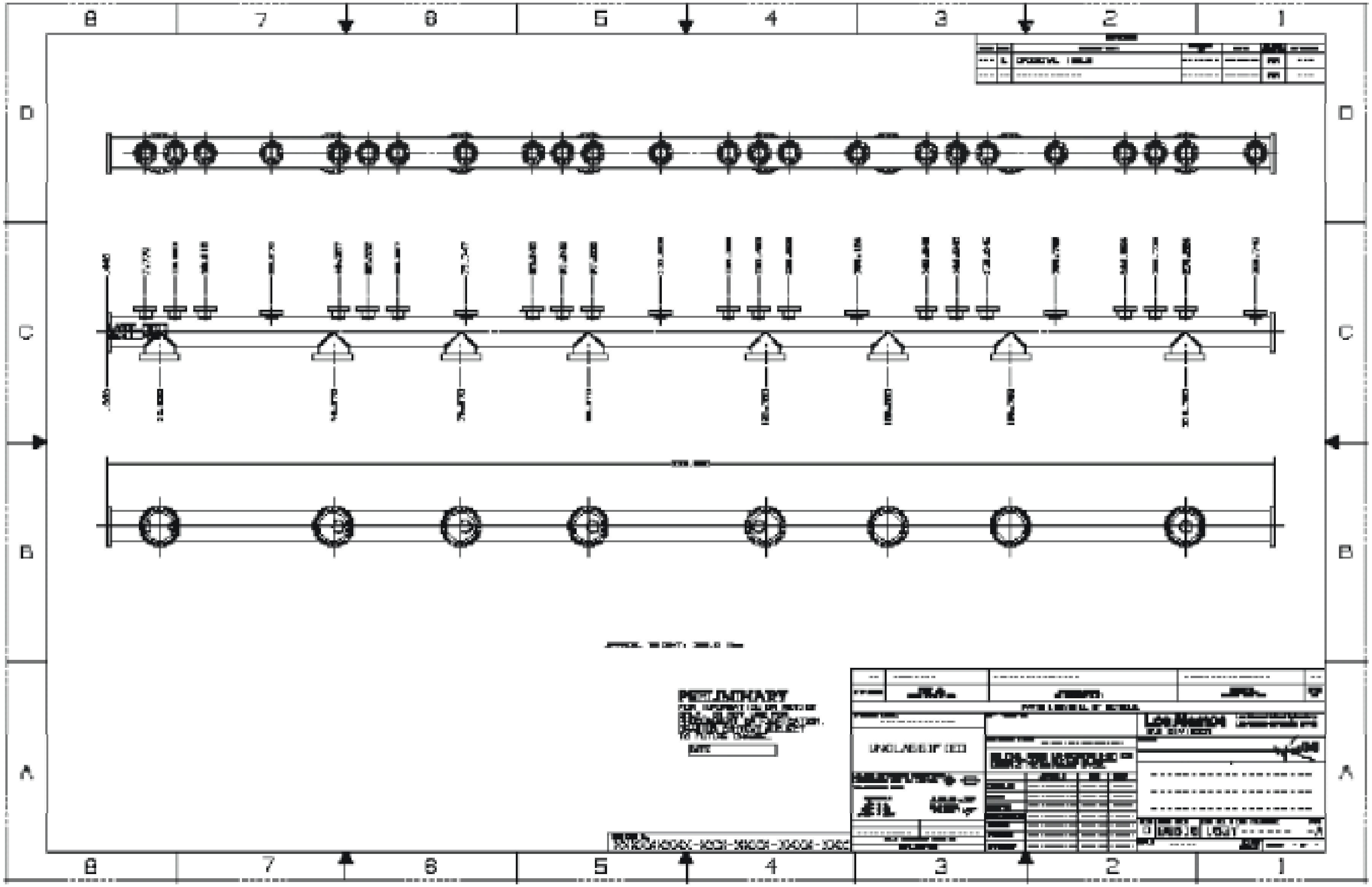
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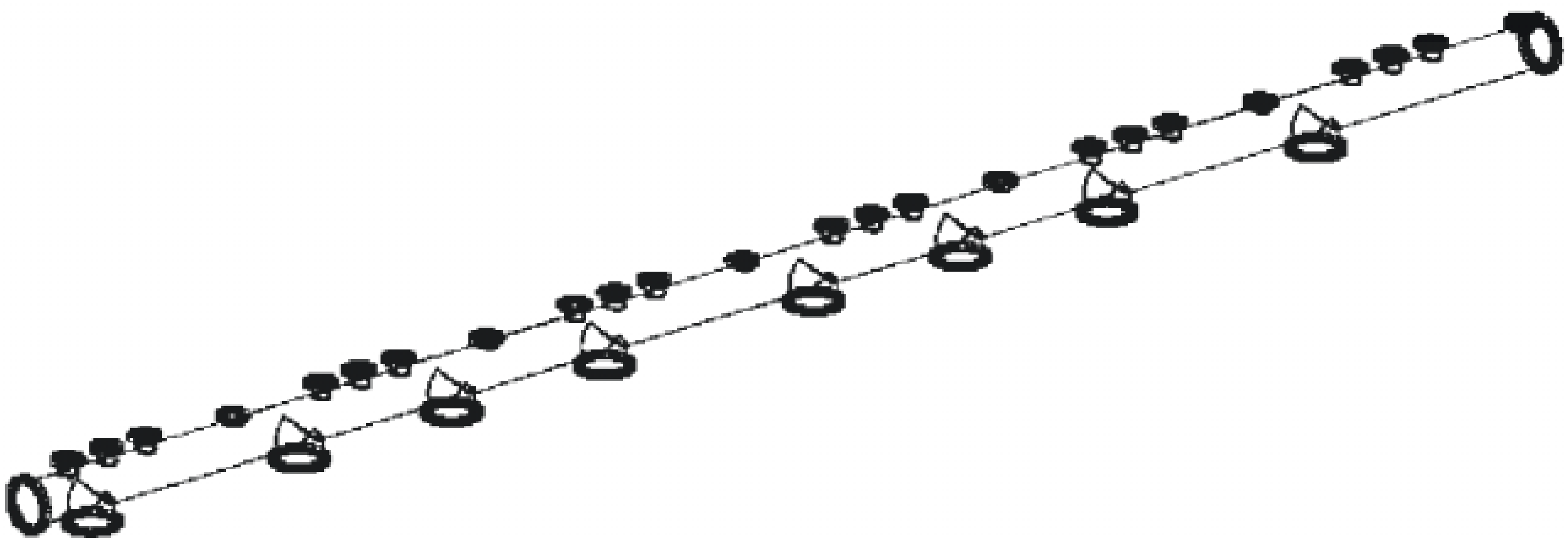

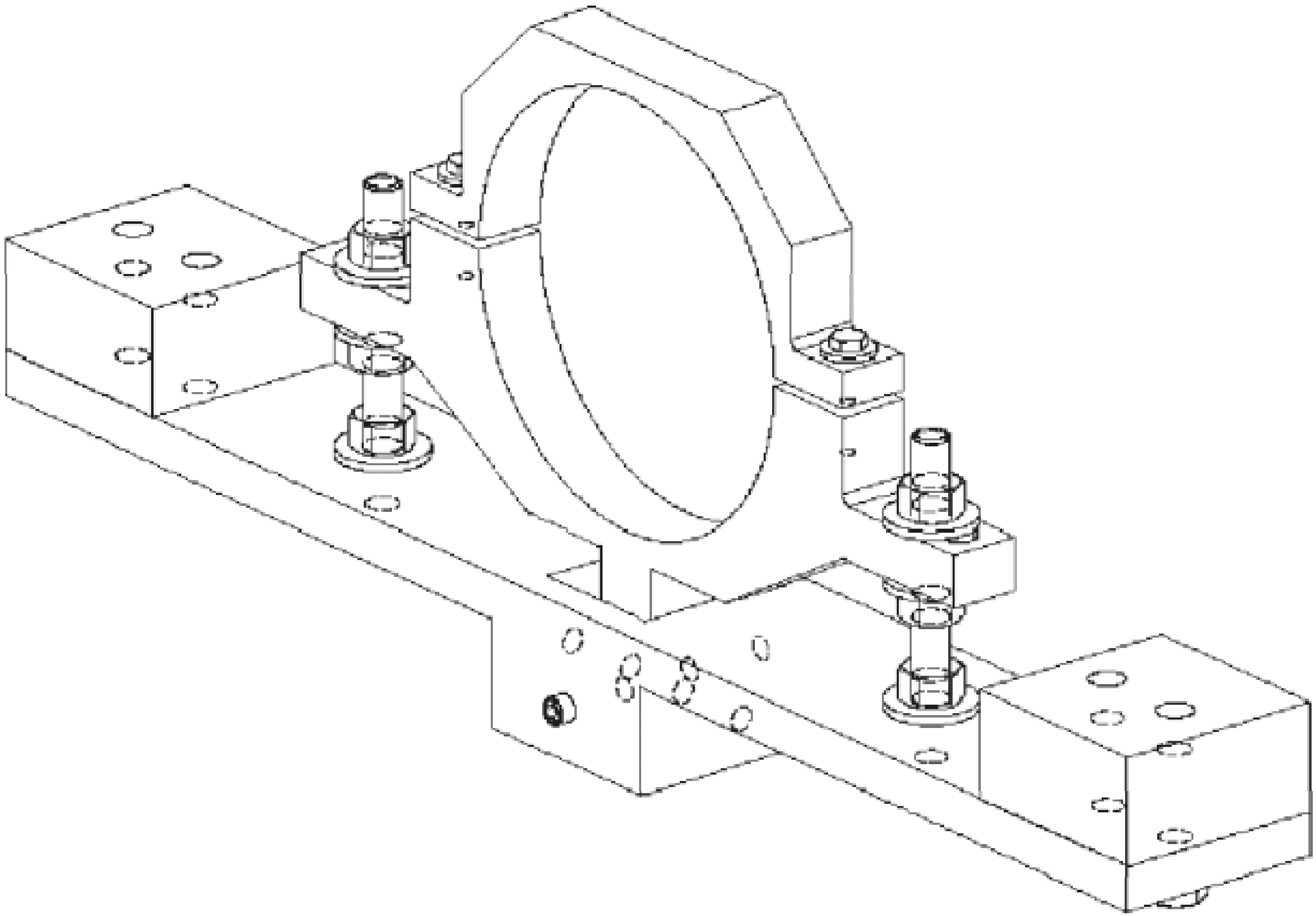

16.0 Appendix D – Signal-Device Name List

Device and Signal Name List for CCL Module 1										12/11/00
System/Subsystem	**Device Name**	**Device**	**Manufacturer**	**Model #**	**Signal Type**	**Signal name**	**Location**	**Module Info**	**Cable/Pair**	**Comment**
								(PLC)		
CCL_Vac1	SP-101	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-101:Cmd_str				Ladder logic start pump command
CCL_Vac1	SP-101	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-101:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	SP-101	Scroll Pump			24 vac	CCL_Vac1:SP-101:Ctl_run	CCL1 Manifold A	output		Control - Start/stop pump
CCL_Vac1	SP-101	Scroll Pump			24 vdc	CCL_Vac1:SP-101:OL	CCL1 Manifold A	input		Thermal overload
CCL_Vac1	SP-101	Scroll Pump			24 vdc	CCL_Vac1:SP-101:Sts_aux	CCL1 Manifold A	input		Run/Stop status
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_str				Ladder logic start pump command
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_nrm				Ladder logic normal speed command
CCL_Vac1	TP-103	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-103:Cmd_ls				Ladder logic low speed command
CCL_Vac1	TP-103	Turbo pump			relay contact	CCL_Vac1:TP-103:Ctl_run	CCL1 Manifold A	output		Control - start/stop pump
CCL_Vac1	TP-103	Turbo pump			relay contact	CCL_Vac1:TP-103:Ctl_ls	CCL1 Manifold A	output		Control - Normal/low speed
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sts_run	CCL1 Manifold A	input		Run/stop status
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sts_ls	CCL1 Manifold A	input		Normal/low speed status
CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Fault	CCL1 Manifold A	input		Normal/fault status
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CCL_Vac1	TP-103	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-103:Sp_02	CCL1 Manifold A	input		Operating speed setpoint 2
CCL_Vac1	CC-105	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-105:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-105	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-105:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-105	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-105:Ctl_on	Turbo cart	output		Control - CCG on/off
CCL_Vac1	CC-105	Cold Cathode Gauge			0-10v analog	CCL_Vac1:CC-105:P	Turbo cart	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-105	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-105:Sp_01	Turbo cart	input		Ion Gauge pressure setpoint 1
CCL_Vac1	TC-103	Convectron			0-10v analog	CCL_Vac1:TC-103:P	Turbo cart	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-103	Convectron			24 vdc	CCL_Vac1:TC-103:Sp_01	Turbo cart	input		Convectron pressure setpoint 1
CCL_Vac1	CC-103	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-103:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-103	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-103:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-103	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-103:Ctl_on	CCL1 Manifold A	output		Control - CCG on/off
CCL_Vac1	CC-103	Cold Cathode Gauge			0-10v analog	CCL_Vac1:CC-103:P	CCL1 Manifold A	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-103	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-103:Sp_01	CCL1 Manifold A	input		Ion Gauge pressure setpoint 1
CCL_Vac1	TC-101	Convectron			0-10v analog	CCL_Vac1:TC-101:P	CCL1 Manifold A	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-101	Convectron			24 vdc	CCL_Vac1:TC-101:Sp_01	CCL1 Manifold A	input		Convectron pressure setpoint 1
CCL_Vac1	RGA-101	Partial pressure analyzer			RS-232	CCL_Vac1:RGA-101	CCL1 Manifold A			Partial pressure analyzer
CCL_Vac1	PSV-101	Pressure Safety Valve					CCL1 Manifold A			Pressure relief for purge
CCL_Vac1	MV-101	Manual Valve					CCL1 Manifold A			Vent valve to atmosphere
CCL_Vac1	MV-102	Manual Valve					CCL1 Manifold A			Purge gas inlet valve
CCL_Vac1	MV-105	Manual Valve					Gas Press. Cart			Purge line vent valve to atmosphere
CCL_Vac1	FO-101	Flow Orifice					Gas Press. Cart			Flow restriction to prevent over-pressurization
CCL_Vac1	GV-103	Gate Valve			PLC Internal Logic	CCL_Vac1:GV-103:Cmd_opn				Ladder logic open valve command
CCL_Vac1	GV-103	Gate Valve			PLC Internal Logic	CCL_Vac1:GV-103:Cmd_cls				Ladder logic close valve command
CCL_Vac1	GV-103	Gate Valve			24 vdc	CCL_Vac1:GV-103:Sol	CCL1 Manifold A	output		Solenoid to Open/close valve
CCL_Vac1	GV-103	Gate Valve			24 vdc	CCL_Vac1:GV-103:Pos0	CCL1 Manifold A	input		Position indicator
CCL_Vac1	GV-103	Gate Valve			24 vdc	CCL_Vac1:GV-103:Pos1	CCL1 Manifold A	input		Position indicator

CCL_Vac1	SGV-101	Sector Gate Valve			PLC Internal Logic	CCL_Vac1:SGV-101:Cmd_opn				Ladder logic open valve command
CCL_Vac1	SGV-101	Sector Gate Valve			PLC Internal Logic	CCL_Vac1:SGV-101:Cmd_cls				Ladder logic close valve command
CCL_Vac1	SGV-101	Sector Gate Valve			24 vdc	CCL_Vac1:SGV-101:Sol	CCL1	output		Open/close valve
CCL_Vac1	SGV-101	Sector Gate Valve			24 vdc	CCL_Vac1:SGV-101:Pos0	CCL1	input		Position indicator
CCL_Vac1	SGV-101	Sector Gate Valve			24 vdc	CCL_Vac1:SGV-101:Pos1	CCL1	input		Position indicator
CCL_Vac1	IP-101	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-101:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-101	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-101:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-101	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-101:Ctl_HV	CCL1 Manifold A	output		Control - Turn high voltage on/off
CCL_Vac1	IP-101	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-101:Sts_HV	CCL1 Manifold A	input		Status - High voltage on/off
CCL_Vac1	IP-101	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-101:Sts_Prot	CCL1 Manifold A	input		Start/protect status
CCL_Vac1	IP-101	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-101:Fault	CCL1 Manifold A	input		Normal/fault
CCL_Vac1	IP-101	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-101:V	CCL1 Manifold A	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-101	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-101:I	CCL1 Manifold A	input		Logarithmic output porportional to current
CCL_Vac1	IP-102	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-102:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-102	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-102:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-102	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-102:Ctl_HV	CCL1 Manifold A	output		Control - Turn high voltage on/off
CCL_Vac1	IP-102	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-102:Sts_HV	CCL1 Manifold A	input		Status - High voltage on/off
CCL_Vac1	IP-102	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-102:Sts_Prot	CCL1 Manifold A	input		Start/protect status
CCL_Vac1	IP-102	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-102:Fault	CCL1 Manifold A	input		Normal/fault
CCL_Vac1	IP-102	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-102:V	CCL1 Manifold A	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-102	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-102:I	CCL1 Manifold A	input		Logarithmic output proportional to current
CCL_Vac1	IP-103	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-103:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-103	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-103:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-103	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-103:Ctl_HV	CCL1 Manifold A	output		Control - Turn high voltage on/off
CCL_Vac1	IP-103	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-103:Sts_HV	CCL1 Manifold A	input		Status - High voltage on/off
CCL_Vac1	IP-103	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-103:Sts_Prot	CCL1 Manifold A	input		Start/protect status
CCL_Vac1	IP-103	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-103:Fault	CCL1 Manifold A	input		Normal/fault
CCL_Vac1	IP-103	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-103:V	CCL1 Manifold A	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-103	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-103:I	CCL1 Manifold A	input		Logarithmic output proportional to current
CCL_Vac1	IP-104	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-104:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-104	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-104:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-104	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-104:Ctl_HV	CCL1 Manifold A	output		Control - Turn high voltage on/off
CCL_Vac1	IP-104	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-104:Sts_HV	CCL1 Manifold A	input		Status - High voltage on/off
CCL_Vac1	IP-104	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-104:Sts_Prot	CCL1 Manifold A	input		Start/protect status
CCL_Vac1	IP-104	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-104:Fault	CCL1 Manifold A	input		Normal/fault
CCL_Vac1	IP-104	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-104:V	CCL1 Manifold A	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-104	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-104:I	CCL1 Manifold A	input		Logarithmic output porportional to current
CCL_Vac1	IP-105	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-105:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-105	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-105:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-105	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-105:Ctl_HV	CCL1 Manifold A	output		Control - Turn high voltage on/off
CCL_Vac1	IP-105	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-105:Sts_HV	CCL1 Manifold A	input		Status - High voltage on/off
CCL_Vac1	IP-105	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-105:Sts_Prot	CCL1 Manifold A	input		Start/protect status
CCL_Vac1	IP-105	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-105:Fault	CCL1 Manifold A	input		Normal/fault
CCL_Vac1	IP-105	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-105:V	CCL1 Manifold A	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-105	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-105:I	CCL1 Manifold A	input		Logarithmic output proportional to current

CCL_Vac1	SP-102	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-102:Cmd_str				Ladder logic start pump command
CCL_Vac1	SP-102	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-102:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	SP-102	Scroll Pump			24 vac	CCL_Vac1:SP-102:Ctl_run	CCL1 Manifold B	output		Control - Start/stop pump
CCL_Vac1	SP-102	Scroll Pump			24 vdc	CCL_Vac1:SP-102:OL	CCL1 Manifold B	input		Thermal overload
CCL_Vac1	SP-102	Scroll Pump			24 vdc	CCL_Vac1:SP-102:Sts_aux	CCL1 Manifold B	input		Run/Stop status
CCL_Vac1	TP-104	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-104:Cmd_str				Ladder logic start pump command
CCL_Vac1	TP-104	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-104:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	TP-104	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-104:Cmd_nrm				Ladder logic normal speed command
CCL_Vac1	TP-104	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-104:Cmd_ls				Ladder logic low speed command
CCL_Vac1	TP-104	Turbo pump			relay contact	CCL_Vac1:TP-104:Ctl_run	CCL1 Manifold B	output		Control - start/stop pump
CCL_Vac1	TP-104	Turbo pump			relay contact	CCL_Vac1:TP-104:Ctl_ls	CCL1 Manifold B	output		Control - Normal/low speed
CCL_Vac1	TP-104	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-104:Sts_run	CCL1 Manifold B	input		Run/stop status
CCL_Vac1	TP-104	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-104:Sts_ls	CCL1 Manifold B	input		Normal/low speed status
CCL_Vac1	TP-104	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-104:Fault	CCL1 Manifold B	input		Normal/fault status
CCL_Vac1	TP-104	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-104:Sp_01	CCL1 Manifold B	input		Operating speed setpoint 1
CCL_Vac1	TP-104	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-104:Sp_02	CCL1 Manifold B	input		Operating speed setpoint 2
CCL_Vac1	CC-106	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-106:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-106	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-106:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-106	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-106:Ctl_on	Turbo cart	output		Control - CCG on/off
CCL_Vac1	CC-106	Cold Cathode Gauge			0-10v analog	CCL_Vac1:CC-106:P	Turbo cart	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-106	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-106:Sp_01	Turbo cart	input		Ion Gauge pressure setpoint 1
CCL_Vac1	TC-104	Convectron			0-10v analog	CCL_Vac1:TC-104:P	Turbo cart	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-104	Convectron			24 vdc	CCL_Vac1:TC-104:Sp_01	Turbo cart	input		Convectron pressure setpoint 1
CCL_Vac1	CC-104	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-104:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-104	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-104:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-104	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-104:Ctl_on	CCL1 Manifold B	output		Control - CCG on/off
CCL_Vac1	CC-104	Cold Cathode Gauge			0-10v analog	CCL_Vac1:CC-104:P	CCL1 Manifold B	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-104	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-104:Sp_01	CCL1 Manifold B	input		Ion Gauge pressure setpoint 1
CCL_Vac1	TC-102	Convectron			0-10v analog	CCL_Vac1:TC-102:P	CCL1 Manifold B	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-102	Convectron			24 vdc	CCL_Vac1:TC-102:Sp_01	CCL1 Manifold B	input		Convectron pressure setpoint 1
CCL_Vac1	PSV-102	Pressure Safety Valve					CCL1 Manifold B			Pressure relief for purge
CCL_Vac1	MV-103	Manual Valve					CCL1 Manifold B			Vent valve to atmosphere
CCL_Vac1	MV-104	Manual Valve					CCL1 Manifold B			Purge gas inlet valve
CCL_Vac1	MV-106	Manual Valve					Gas Press. Cart			Purge line vent valve to atmosphere
CCL_Vac1	FO-102	Flow restrictor					Gas Press. Cart			
CCL_Vac1	GV-104	Gate Valve			PLC Internal Logic	CCL_Vac1:GV-104:Cmd_opn				Ladder logic open valve command
CCL_Vac1	GV-104	Gate Valve			PLC Internal Logic	CCL_Vac1:GV-104:Cmd_cls				Ladder logic close valve command
CCL_Vac1	GV-104	Gate Valve			24 vdc	CCL_Vac1:GV-104:Sol	CCL1 Manifold B	output		Solenoid to Open/close valve
CCL_Vac1	GV-104	Gate Valve			24 vdc	CCL_Vac1:GV-104:Pos0	CCL1 Manifold B	input		Position indicator
CCL_Vac1	GV-104	Gate Valve			24 vdc	CCL_Vac1:GV-104:Pos1	CCL1 Manifold B	input		Position indicator

CCL_Vac1	IP-106	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-106:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-106	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-106:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-106	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-106:Ctl_HV	CCL1 Manifold B	output		Control - Turn high voltage on/off
CCL_Vac1	IP-106	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-106:Sts_HV	CCL1 Manifold B	input		Status - High voltage on/off
CCL_Vac1	IP-106	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-106:Sts_Prot	CCL1 Manifold B	input		Start/protect status
CCL_Vac1	IP-106	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-106:Fault	CCL1 Manifold B	input		Normal/fault
CCL_Vac1	IP-106	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-106:V	CCL1 Manifold B	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-106	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-106:I	CCL1 Manifold B	input		Logarithmic output porportional to current
CCL_Vac1	IP-107	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-107:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-107	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-107:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-107	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-107:Ctl_HV	CCL1 Manifold B	output		Control - Turn high voltage on/off
CCL_Vac1	IP-107	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-107:Sts_HV	CCL1 Manifold B	input		Status - High voltage on/off
CCL_Vac1	IP-107	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-107:Sts_Prot	CCL1 Manifold B	input		Start/protect status
CCL_Vac1	IP-107	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-107:Fault	CCL1 Manifold B	input		Normal/fault
CCL_Vac1	IP-107	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-107:V	CCL1 Manifold B	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-107	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-107:I	CCL1 Manifold B	input		Logarithmic output proportional to current
CCL_Vac1	IP-108	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-108:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-108	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-108:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-108	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-108:Ctl_HV	CCL1 Manifold B	output		Control - Turn high voltage on/off
CCL_Vac1	IP-108	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-108:Sts_HV	CCL1 Manifold B	input		Status - High voltage on/off
CCL_Vac1	IP-108	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-108:Sts_Prot	CCL1 Manifold B	input		Start/protect status
CCL_Vac1	IP-108	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-108:Fault	CCL1 Manifold B	input		Normal/fault
CCL_Vac1	IP-108	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-108:V	CCL1 Manifold B	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-108	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-108:I	CCL1 Manifold B	input		Logarithmic output proportional to current
CCL_Vac1	IP-109	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-109:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-109	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-109:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-109	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-109:Ctl_HV	CCL1 Manifold B	output		Control - Turn high voltage on/off
CCL_Vac1	IP-109	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-109:Sts_HV	CCL1 Manifold B	input		Status - High voltage on/off
CCL_Vac1	IP-109	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-109:Sts_Prot	CCL1 Manifold B	input		Start/protect status
CCL_Vac1	IP-109	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-109:Fault	CCL1 Manifold B	input		Normal/fault
CCL_Vac1	IP-109	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-109:V	CCL1 Manifold B	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-109	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-109:I	CCL1 Manifold B	input		Logarithmic output porportional to current
CCL_Vac1	IP-110	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-110:Cmd_str				Ladder logic start pump command
CCL_Vac1	IP-110	Ion pump 300 L/s			PLC Internal Logic	CCL_Vac1:IP-110:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	IP-110	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-110:Ctl_HV	CCL1 Manifold B	output		Control - Turn high voltage on/off
CCL_Vac1	IP-110	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-110:Sts_HV	CCL1 Manifold B	input		Status - High voltage on/off
CCL_Vac1	IP-110	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-110:Sts_Prot	CCL1 Manifold B	input		Start/protect status
CCL_Vac1	IP-110	Ion pump 300 L/s			24 vdc	CCL_Vac1:IP-110:Fault	CCL1 Manifold B	input		Normal/fault
CCL_Vac1	IP-110	Ion pump 300 L/s			0-10v analog in	CCL_Vac1:IP-110:V	CCL1 Manifold B	input		Linear output from pump proportional to voltage
CCL_Vac1	IP-110	Ion pump 300 L/s			0-5 analog in	CCL_Vac1:IP-110:I	CCL1 Manifold B	input		Logarithmic output proportional to current
CCL_Vac1	CC-101	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-101:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-101	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-101:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-101	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-101:Ctl_on	CCL1 RF window A	output		Control - IG1 on/off
CCL_Vac1	CC-101	Cold Cathode Gauge			0-10v analog in	CCL_Vac1:CC-101:P	CCL1 RF window A	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-101	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-101:Sp_01	CCL1 RF window A	input		Gauge pressure setpoint 1

CCL_Vac1	NP-101	NEG pump			PLC Internal Logic	CCL_Vac1:NP-101:Cmd_Rgn_on				Ladder logic start regen command
CCL_Vac1	NP-101	NEG pump			PLC Internal Logic	CCL_Vac1:NP-101:Cmd_Rgn_off				Ladder logic stop regen command
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:Ctl_rgn_on	CCL1 RF window A	output		Control - start regen
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:Ctl_rgn_off	CCL1 RF window A	output		Control - stop regen
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:Ctl_rgn_enb	CCL1 RF window A	output		Control - regen enable
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:Sts_temp	CCL1 RF window A	input		Status - regen temperature alarm
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:OI	CCL1 RF window A	input		Status - regen power supply over-current alarm
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:OT	CCL1 RF window A	input		Status - regen power supply overtemp alarm
CCL_Vac1	NP-101	NEG pump			24 vdc	CCL_Vac1:NP-101:Sts_inlk	CCL1 RF window A	input		Status - regen interlock
CCL_Vac1	NP-101	NEG pump			0-20mA analog out	CCL_Vac1:NP-101:Ctl_T	CCL1 RF window A	output		Control - remote temperature setpoint
CCL_Vac1	NP-101	NEG pump			4-20mA analog in	CCL_Vac1:NP-101:T	CCL1 RF window A	input		NEG regen temperature
CCL_Vac1	GV-101	Pneumatic Gate Valve			PLC Internal Logic	CCL_Vac1:GV-101:Cmd_opn				Ladder logic open valve command
CCL_Vac1	GV-101	Pneumatic Gate Valve			PLC Internal Logic	CCL_Vac1:GV-101:Cmd_cls				Ladder logic close valve command
CCL_Vac1	GV-101	Pneumatic Gate Valve			24 vdc	CCL_Vac1:GV-101:Sol	CCL1 RF window A	output		Solenoid to Open/close valve
CCL_Vac1	GV-101	Pneumatic Gate Valve			24 vdc	CCL_Vac1:GV-101:Pos0	CCL1 RF window A	input		Position indicator
CCL_Vac1	GV-101	Pneumatic Gate Valve			24 vdc	CCL_Vac1:GV-101:Pos1	CCL1 RF window A	input		Position indicator
CCL_Vac1	TP-101	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-101:Cmd_str				Ladder logic start pump command
CCL_Vac1	TP-101	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-101:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	TP-101	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-101:Cmd_nrm				Ladder logic normal speed command
CCL_Vac1	TP-101	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-101:Cmd_ls				Ladder logic low speed command
CCL_Vac1	TP-101	Turbo pump			relay contact	CCL_Vac1:TP-101:Ctl_run	CCL1 RF window A	output		Control - start/stop pump
CCL_Vac1	TP-101	Turbo pump			relay contact	CCL_Vac1:TP-101:Ctl_ls	CCL1 RF window A	output		Control - Normal/low speed
CCL_Vac1	TP-101	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-101:Sts_run	CCL1 RF window A	input		Run/stop status
CCL_Vac1	TP-101	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-101:Sts_ls	CCL1 RF window A	input		Normal/low speed status
CCL_Vac1	TP-101	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-101:Fault	CCL1 RF window A	input		Normal/fault status
CCL_Vac1	TP-101	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-101:Sp_01	CCL1 RF window A	input		Operating speed setpoint 1
CCL_Vac1	TP-101	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-101:Sp_02	CCL1 RF window A	input		Operating speed setpoint 2
CCL_Vac1	CC-102	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-102:Cmd_on				Ladder logic - gauge on command
CCL_Vac1	CC-102	Cold Cathode Gauge			PLC Internal Logic	CCL_Vac1:CC-102:Cmd_off				Ladder logic - gauge off command
CCL_Vac1	CC-102	Cold Cathode Gauge			relay contact	CCL_Vac1:CC-102:Ctl_on	CCL1 RF window B	output		Control - IG1 on/off
CCL_Vac1	CC-102	Cold Cathode Gauge			0-10v analog in	CCL_Vac1:CC-102:P	CCL1 RF window B	input		Logarithmic output proportional to pressure
CCL_Vac1	CC-102	Cold Cathode Gauge			24 vdc	CCL_Vac1:CC-102:Sp_01	CCL1 RF window B	input		Gauge pressure setpoint 1
CCL_Vac1	NP-102	NEG pump			PLC Internal Logic	CCL_Vac1:NP-102:Cmd_Rgn_on				Ladder logic start regen command
CCL_Vac1	NP-102	NEG pump			PLC Internal Logic	CCL_Vac1:NP-102:Cmd_Rgn_off				Ladder logic stop regen command
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:Ctl_rgn_on	CCL1 RF window B	output		Control - start regen
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:Ctl_rgn_off	CCL1 RF window B	output		Control - stop regen
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:Ctl_rgn_enb	CCL1 RF window B	output		Control - regen enable
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:Sts_temp	CCL1 RF window B	input		Status - regen temperature alarm
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:OI	CCL1 RF window B	input		Status - regen power supply over-current alarm
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:OT	CCL1 RF window B	input		Status - regen power supply overtemp alarm
CCL_Vac1	NP-102	NEG pump			24 vdc	CCL_Vac1:NP-102:Sts_inlk	CCL1 RF window B	input		Status - regen interlock
CCL_Vac1	NP-102	NEG pump			0-20mA analog out	CCL_Vac1:NP-102:Ctl_T	CCL1 RF window B	output		Control - remote temperature setpoint
CCL_Vac1	NP-102	NEG pump			4-20mA analog in	CCL_Vac1:NP-102:T	CCL1 RF window B	input		NEG regen temperature
CCL_Vac1	GV-102	Pneumatic Gate Valve			PLC Internal Logic	CCL_Vac1:GV-102:Cmd_opn				Ladder logic open valve command
CCL_Vac1	GV-102	Pneumatic Gate Valve			PLC Internal Logic	CCL_Vac1:GV-102:Cmd_cls				Ladder logic close valve command
CCL_Vac1	GV-102	Pneumatic Gate Valve			24 vdc	CCL_Vac1:GV-102:Sol	CCL1 RF window B	output		Solenoid to Open/close valve
CCL_Vac1	GV-102	Pneumatic Gate Valve			24 vdc	CCL_Vac1:GV-102:Pos0	CCL1 RF window B	input		Position indicator
CCL_Vac1	GV-102	Pneumatic Gate Valve			24 vdc	CCL_Vac1:GV-102:Pos1	CCL1 RF window B	input		Position indicator

CCL_Vac1	TP-102	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-102:Cmd_str				Ladder logic start pump command
CCL_Vac1	TP-102	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-102:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	TP-102	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-102:Cmd_nrm				Ladder logic normal speed command
CCL_Vac1	TP-102	Turbo pump			PLC Internal Logic	CCL_Vac1:TP-102:Cmd_ls				Ladder logic low speed command
CCL_Vac1	TP-102	Turbo pump			relay contact	CCL_Vac1:TP-102:Ctl_run	CCL 1 RF window B	output		Control - start/stop pump
CCL_Vac1	TP-102	Turbo pump			relay contact	CCL_Vac1:TP-102:Ctl_ls	CCL 1 RF window B	output		Control - Normal/low speed
CCL_Vac1	TP-102	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-102:Sts_run	CCL 1 RF window B	input		Run/stop status
CCL_Vac1	TP-102	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-102:Sts_ls	CCL 1 RF window B	input		Normal/low speed status
CCL_Vac1	TP-102	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-102:Fault	CCL 1 RF window B	input		Normal/fault status
CCL_Vac1	TP-102	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-102:Sp_01	CCL 1 RF window B	input		Operating speed setpoint 1
CCL_Vac1	TP-102	Turbo pump			24 vdc negative logic	CCL_Vac1:TP-102:Sp_02	CCL 1 RF window B	input		Operating speed setpoint 2
CCL_Vac1	TC-105	Convectron			0-10v analog in	CCL_Vac1:TC-105:P	CCL 1 RF windows	input		Foreline pressure, 10 milliTorr to 760 Torr
CCL_Vac1	TC-105	Convectron			24 vdc	CCL_Vac1:TC-105:Sp_01	CCL 1 RF windows	input		Convectron pressure setpoint 1
CCL_Vac1	MV-107	Manual Valve					CCL 1 RF windows			RF window vent valve to atmosphere
CCL_Vac1	SP-103	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-103:Cmd_str				Ladder logic start pump command
CCL_Vac1	SP-103	Scroll Pump			PLC Internal Logic	CCL_Vac1:SP-103:Cmd_stp				Ladder logic stop pump command
CCL_Vac1	SP-103	Scroll Pump			24 vac	CCL_Vac1:SP-103:Ctl_run	CCL 1 RF windows	output		Control - Start/stop pump
CCL_Vac1	SP-103	Scroll Pump			24 vdc	CCL_Vac1:SP-103:Sts_aux	CCL 1 RF windows	input		Run/Stop status
Totals CCL Module 1 I/O										
relay output		14 channels								
24 vdc output		25 channels								
24 vdc input		64 channels								
24 vdc input negative logic		15 channels								
analog input		32 channels								
analog output		2 channels								

17.0 Appendix E – Hardware Specification Sheets

Preliminary Specification for Turbomolecular Pump Cart

1.0 Scope
The following preliminary specifications are based on the current (9/8/00) vacuum system design. This design uses four turbo pumps per CCL module (based on 6" diameter manifolds for the CCL) and one turbo pump per DTL tank during the initial pump down.

2.0 Mechanical specifications/requirements
The turbo pump cart shall be versatile enough to pump down both the CCL modules and the DTL tanks. Adequate space shall be provided during cart use to allow technicians access to the gate valve/cart interface; this space shall allow the use of standard tools to connect the cart to the gate valve flange. The cart shall be small enough to allow safe passage of personnel through the tunnel during cart use.

2.1 Cart space constraints
The cart space constraints are based on the support structure geometry, the turbo pump port locations, and vacuum system geometry. Other systems (e.g., cooling systems) are not included in the space constraints; hence, interference problems may still exist even if these space constraints are met. Figure 1 gives the space constraints for DTL access. Figure 2 gives the space constraints for CCL access.

Details describing a preliminary quote from Varian based on a modified version of their standard turbo cart are given in Appendix A.

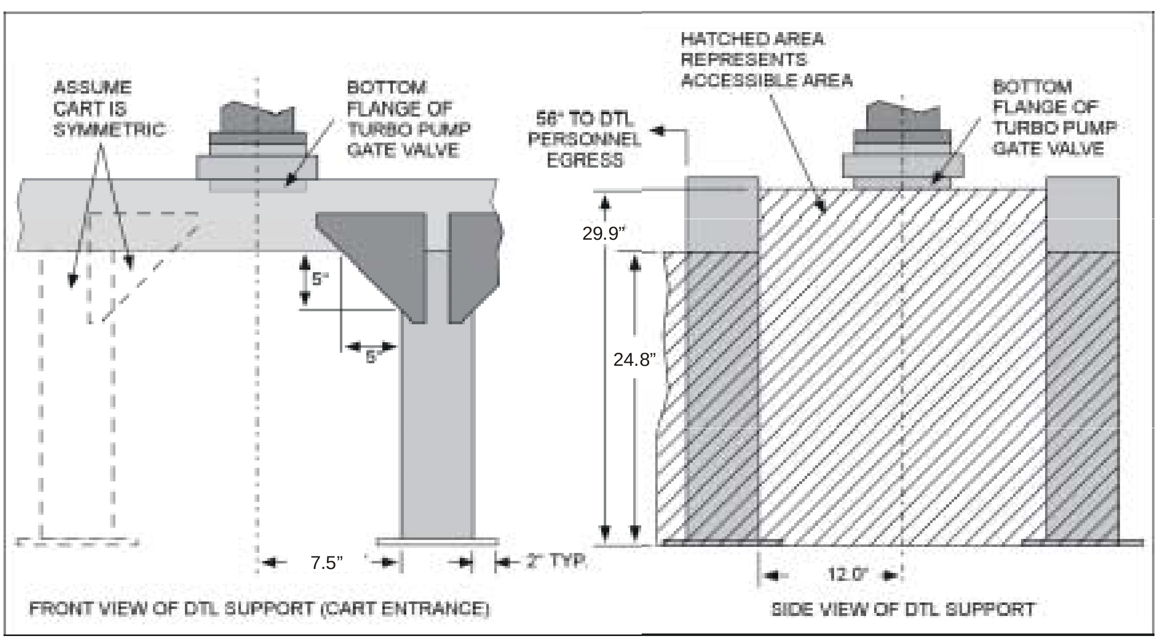


Figure 1: DTL space constraints

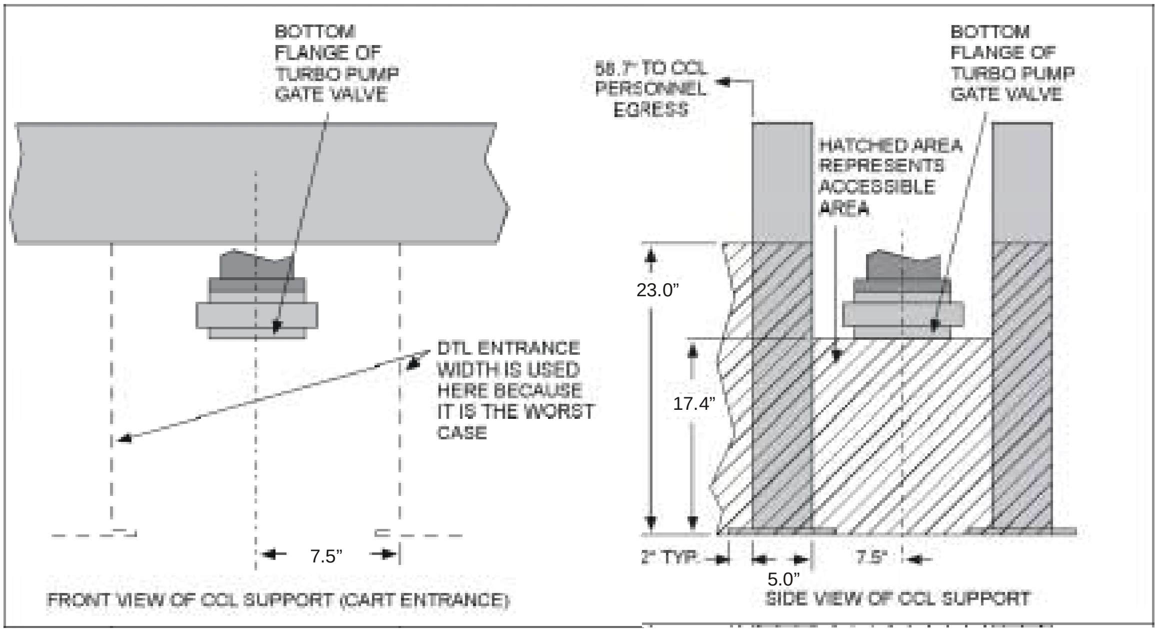


Figure 2: CCL space constraints

2.2 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the turbomolecular pump, primary pump, vacuum gauge, foreline and associated vacuum hardware shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

3.0 Primary (roughing) pump

The primary pump will be oil-free. The primary pump will have a pumping speed of 250 liters/minute while operating at 120 VAC and 60 Hz. The primary pump will have an ultimate base pressure below 10 milliTorr. The mean time between minor maintenance shall be 6000 hours or more. The mean time between major maintenance shall be 12,000 hours or more.

3.1 Primary pump controls

The Primary pump will have an approved (UL or CE) motor starter circuit. A remote normally open contact will control the start/stop function. A closed contact will start the primary pump. If the closed contact were to open, then the primary pump will stop. The motor starter will have an auxiliary contact that is open when the pump is stopped and closed when the pump is running. The motor starter will have a thermal overload that has a normally closed contact. If an overload condition occurs, the contact will open.

4.0 Low vacuum gauge

The turbo pump cart will have a low vacuum gauge mounted on the foreline between the turbo and the scroll pump. This gauge will measure the vacuum pressure by a combination of thermal conductivity and convection. The measurement range of the low vacuum gauge will be from 1000 Torr to 1×10^{-3} Torr.

4.1 High vacuum gauge

The turbo pump cart will have a high vacuum gauge mounted above the turbo. The high vacuum gauge will be an inverted magnetron cold cathode gauge. . The high vacuum gauge will have a 2.75" conflat flange. The measurement range of the high vacuum gauge will be from $1x10^{-3}$ Torr to $1x10^{-10}$ Torr.

A reducing tee with a 1.75" port will be mounted on the inlet of the turbo. The 1.75" port will have a 2.75" conflat flange. The high vacuum gauge will be mounted to this 2.75" conflat flange.

4.2 Vacuum gauge controller

The gauge controller will be able to read both the low and high vacuum gauges simultaneously and will have a local digital display where both pressures are shown. The gauge controller will have an adjustable setpoint for the pressure of each gauge. The setpoint will have a normally open contact that will close when the pressure goes below the setpoint. The gauge controller will have analog outputs each gauge. The analog outputs will be proportional to the pressure that each gauge is reading.

5.0 Turbomolecular pump

The turbomolecular pump will have a pump speed of at least 280 liters/second for nitrogen and 210 liters/second for hydrogen. The turbomolecular pump shall have a compression ratio of at least $2x10^{8}$ for nitrogen and $1x10^{4}$ for hydrogen. The turbomolecular pump will have an 8 inch "conflat" inlet flange. The turbomolecular pump will have ceramic bearings and will be able to operate in any orientation. The turbomolecular pump will have a throughput of at least 60 liters/second at 75 milliTorr for nitrogen. The turbomolecular pump will have a base pressure of $1.5x10^{-10}$ Torr when the foreline pressure is below 7.5 milliTorr.

The turbomolecular pump will have forced air cooling. Water-cooling is not acceptable. The turbomolecular pump will have an automatic fixed delay vent valve.

5.1 Turbomolecular pump controls

The turbomolecular pump will have a controller that can start and stop the pump by a remote contact. When the contact is closed the pump will start and when the contact opens the pump will stop.

The controller will have +24VDC outputs that indicate the status of the turbo pump. One output will indicate the turbomolecular pump is in the startup mode. During startup, the +24 VDC will be present on the output and will return back to 0 VDC once the pump has reached normal operation. One output will indicate that the RPMs of the turbomolecular pump are higher than a programmable setpoint. One output will indicate if there is a fault condition in the turbomolecular pump. The +24 VDC will be present on the output if there is a fault and will be 0 VDC if the pump is operating correctly.

See Figure 3 for a block diagram of the turbo cart.

6.0 Remote Control Interface

The various remote control signals discussed in sections 3.1, 4.0 and 5.1 will be available on a single panel mounted connector on the turbo cart. This connector shall be a multi-pin circular connector that meets military specification MIL-C-26482.

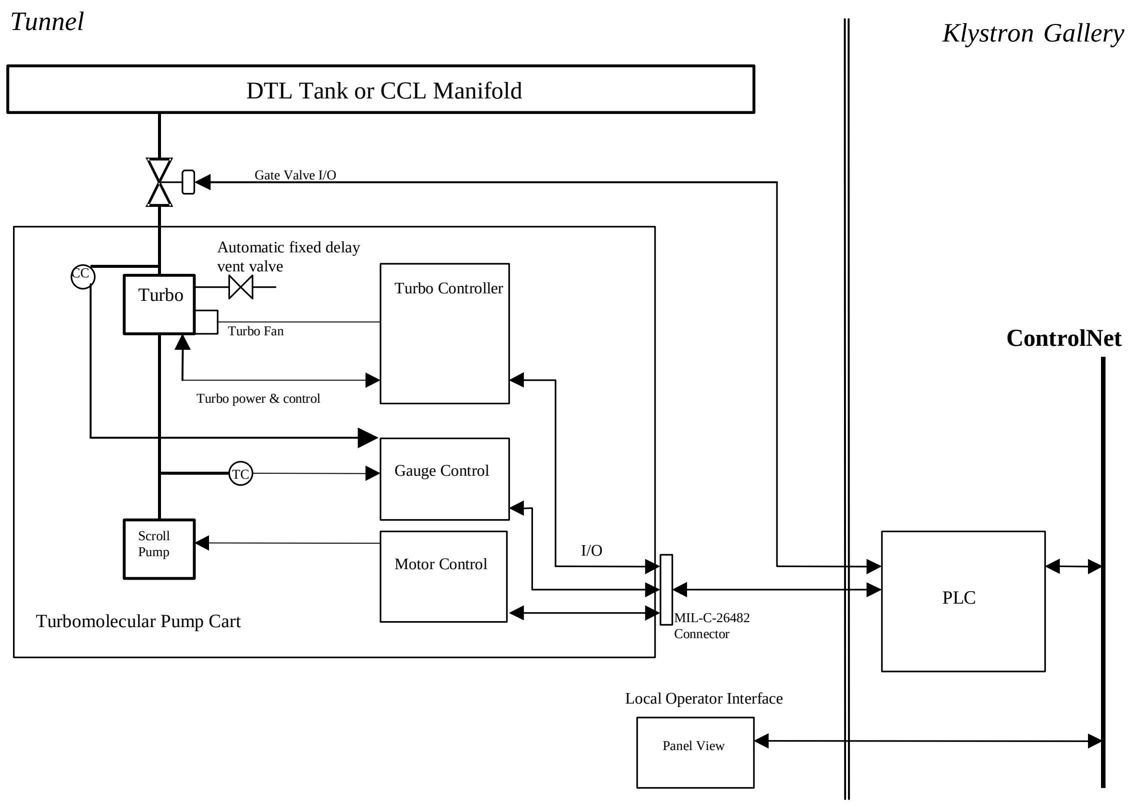


Figure 3. Block diagram of the turbo cart.

Turbo cart quote from Varian

A preliminary cost estimate for a modified Varian turbo cart has been obtained. The cart design was modified to work with the most recent DTL/CCL geometric models available at that time. (Note: These are not the same as LANL's current CCL/DTL geometric models.) The modifications were designed based on the Varian T-series turbo cart (Model number MSPT9040/MSP1505 – 300 l/s turbo & 300 l/min dry scroll primary pump).

The standard T-series cart (Figure A-6) does not fit under the DTL or CCL support structures based on the Varian catalog dimensions and the geometric model of the support structures. Moreover, the DTL and CCL ports were are at different heights. Therefore, modifications to the standard cart are necessary.

Since the standard cart will not fit under the accelerator regardless of orientation, the preliminary specification proposed the simplest changes necessary to get the cart to work with both the DTL and CCL turbo ports.

Figure A-1 shows the modified turbo cart under the CCL structure. Figures A-2 and A-3 show the cart with the turbo pump in both the upper-most and lowermost positions. The range of motion satisfies the installation clearances for both the DTL and CCL configurations. Figure A-4 and A-5 give cart dimensions. Figure A-6 shows the cart in its original, unmodified state.

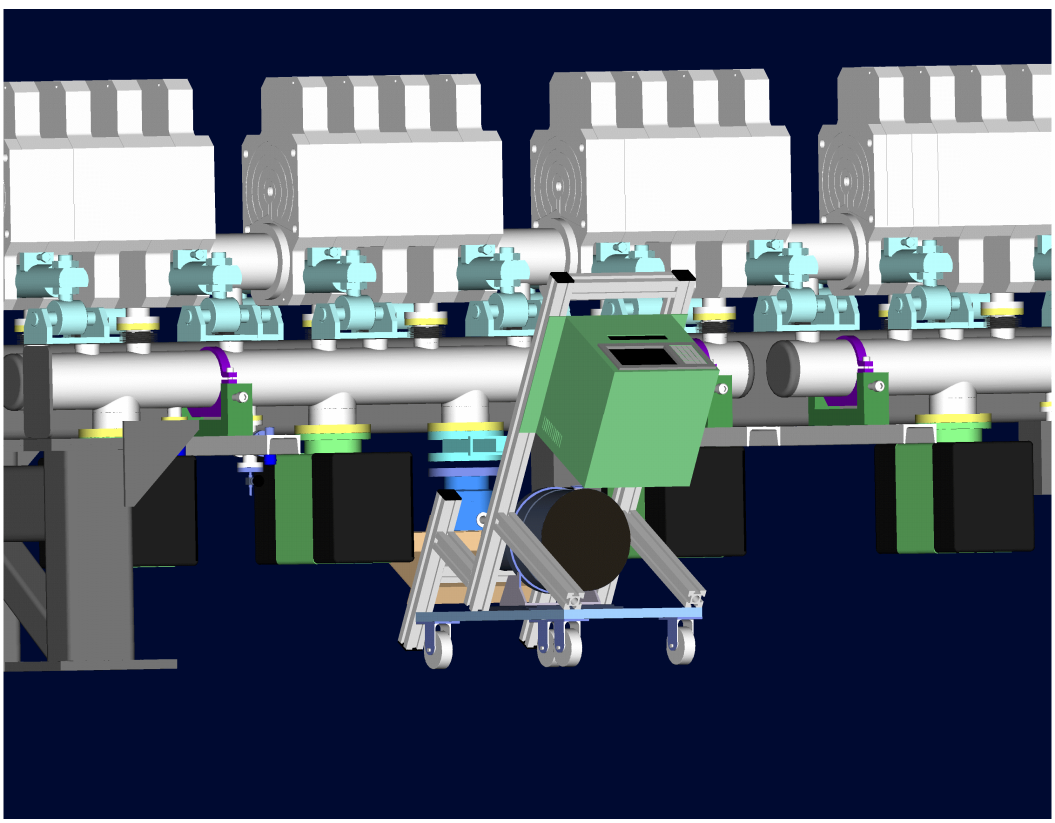


Figure A-1: Modified cart under the CCL structure

Varian turbo cart cost estimate:

Description: Basic turbo cart (T-series turbo pumping cart) with a V300HT turbo pump with 8” CF connection, turbo pump controller and a Triscroll 300 primary pump. Note: the prices listed here are for a turbo pump cart without accessories. These prices do not include quantity discounts.

Unmodified turbo cart:

Turbo pump & cart (MSPT9040)	$10,660
Scroll pump (MSP0202)	$5,195
TOTAL	$15,855

Modified turbo cart:

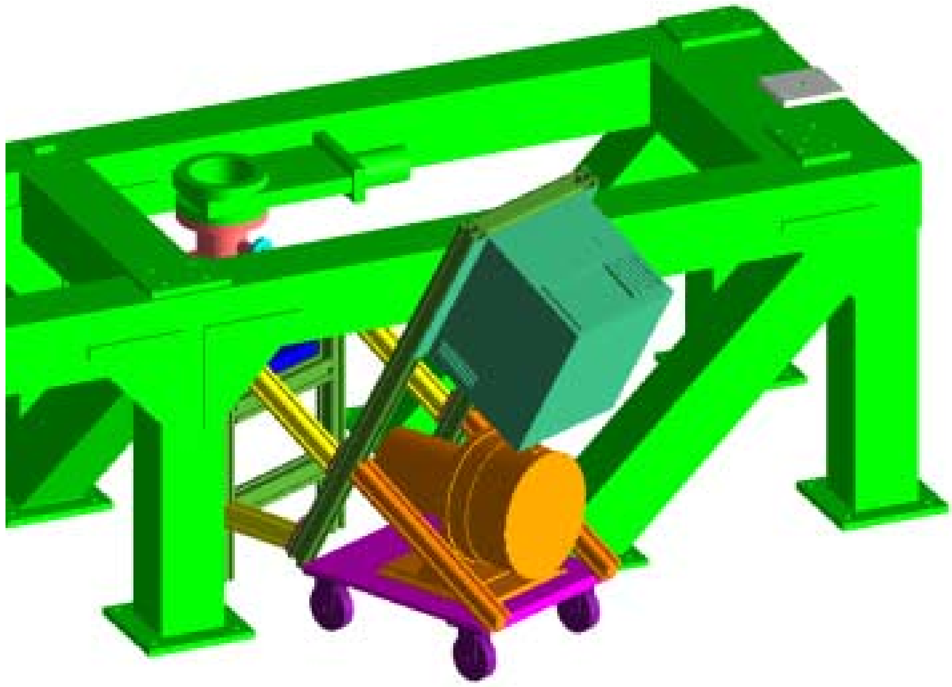
Modified standard product (quote from Varian)	$16,589

Pumps alone:

Turbo pump (V300HT)	$7,260
Controller for turbo	$2,355
Scroll pump (PTS03001)	$5,450
TOTAL	$15,065

Cart costs alone:

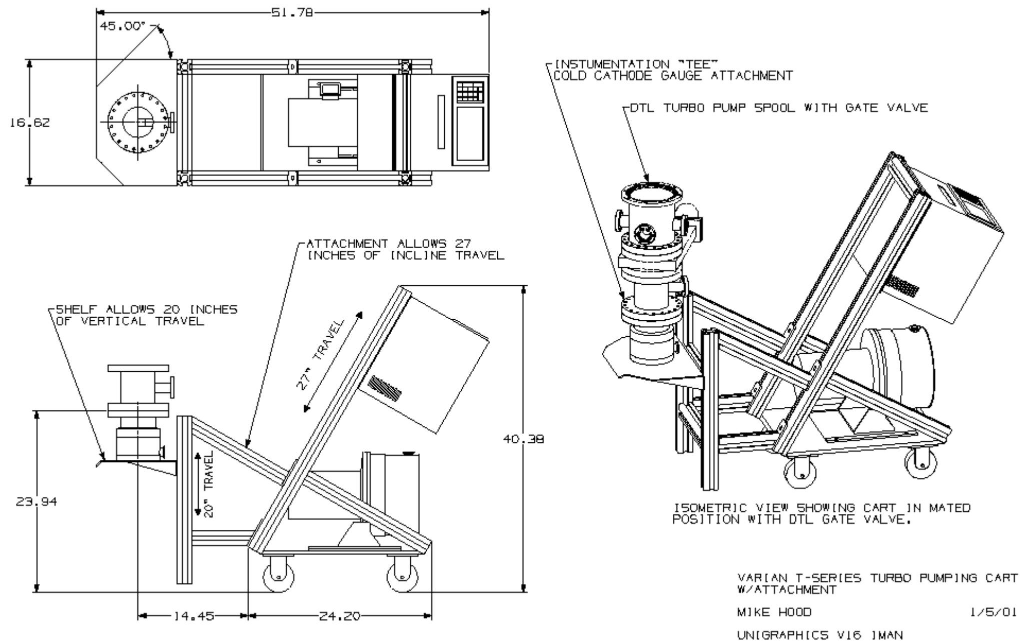
Unmodified:	$15,855-$15,065=	$790
Modifications:	$16,589-$15,855=	$734
TOTAL		$1,524



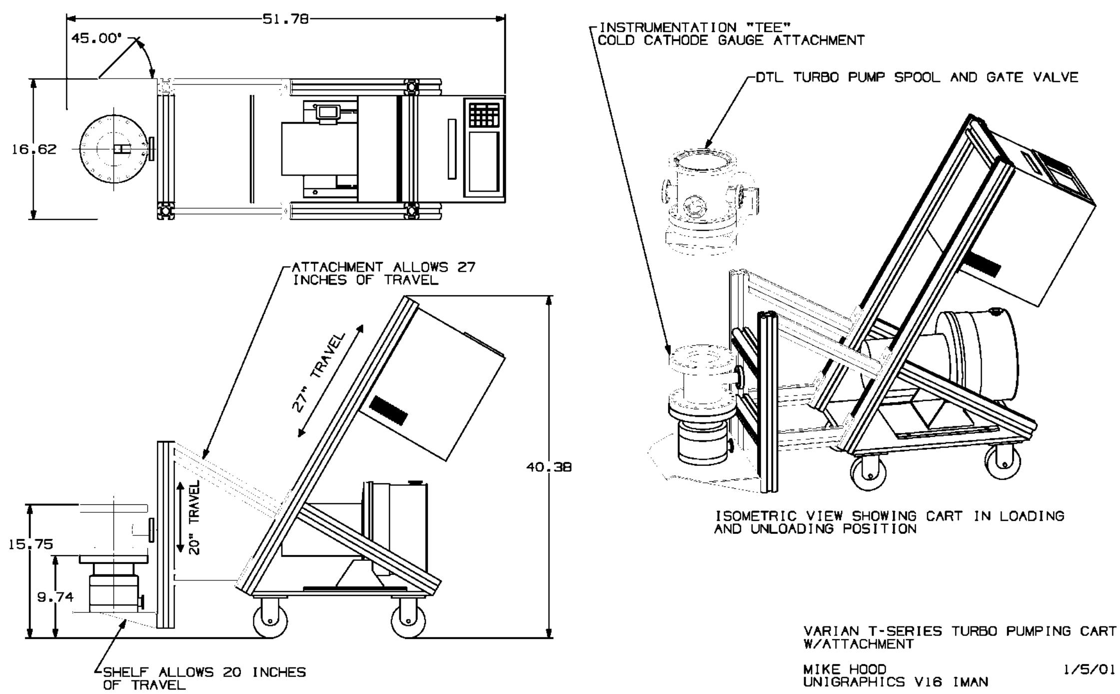
Appendix A-2: Varian Turbo Pumping Cart with support attachment in mated position with the DTL gate valve. Also shown is cart clearance under DTL support structure interference area.

Appendix A-3: Varian Turbo Cart with support attachment in mated position.

Appendix A-4 Varian Turbo Cart with support attachment in mobile position.



Appendix A-5: Detail drawing of Varian Turbo Cart with support attachment mated to the DTL spool and gate valve.



Appendix A-6: Detail drawing of Varian Turbo Cart with support attachment in moblile position.

Appendix A-7: Standard T-series turbo cart.

Ion Pump Specification

1.0 Scope
The following specifications are based on the final DTL and CCL vacuum system designs. These designs uses ten 300 l/s ion pumps per CCL module (modules use 6" diameter vacuum manifolds) and three 300 l/s ion pumps per DTL tank.

2.0 Mechanical specifications/requirements
The same size ion pumps shall be used on both the CCL modules and the DTL tanks. Adequate space shall be provided during pump installation to allow technicians access to the ion pump ports; this space shall allow the use of standard tools to connect the pumps to their flanges. The ion pumps shall have a stainless steel case. The flange on the ion pumps shall be strong enough to support the weight of the pumps. The flanges shall be eight-inch non-rotatable CF flanges. The weight of each ion pump shall not exceed 160 pounds.

2.1 Ion pump space constraints
The ion pump space constraints are based on the support structure geometry, the ion pump port locations, and vacuum system geometry. The height of the ion pumps shall not exceed 17.0 inches. The width of the ion pumps shall not exceed 13.5 inches. The depth of the ion pumps shall not exceed 20.0 inches

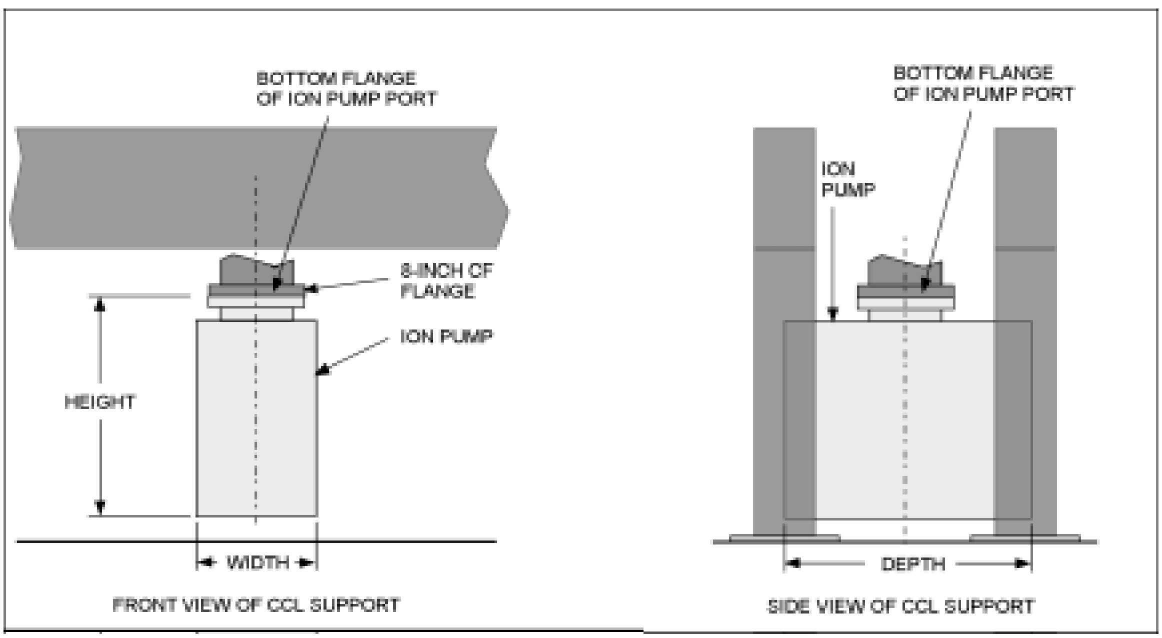


Figure 1: Ion pump dimensions

2.2 Parts, Materials and Processes
The parts, materials and processes used in the manufacturing of the ion pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source

Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

3.0 Ion Pump Design and Performance

The ion pump will be a diode configuration and have a pump speed of at least 300 liters/second for nitrogen at $1x10^{-6}$ Torr. The ion pump shall have a nominal operating life of 40,000 hours at $1x10^{-6}$ Torr.

The ion pump body shall have a leak rate less than $1x10^{-11}$ atm-cc/sec of helium. The ion pump shall have a base pressure below $2x10^{-10}$ Torr.

The cathode shall be operated at ground potential. The ion pump can operate in the range from 3500 to 7000 volts.

The pump shall be capable of withstanding a bakeout to 300º C with the magnets and high voltage connector in place. (The magnetic field strength or pump speed shall not degrade as a result of the 300º C bake.)

3.1 Ion Pump Controller

The ion pump controller output voltage shall be programmable from +3500 to +7000 volts and have an output of at least 100 watts. The ion pump controller output voltage shall have a ripple of less than 0.1%. The ion pump controller shall be able to measure the ion pump current from less than or equal to 100 nA to greater than or equal to 100 mA.

The ion pump controller shall have a remote control option. The remote control option shall have at least the following functions:

> The high voltage shall be turned on and off by a remote normally open contact closure. (When the remote contact closes the high voltage is turned on and when the contact closure opens the voltage is turned off.)
>
> A remote contact closure will select the start mode or protect mode. In the start mode the pump controller will provide its maximum current to start the ion pump at high pressure. In the protect mode the controller will shutdown the high voltage if the current exceeds a preset limit.
>
> The controller will have a normally open contact closure will indicate that the high voltage is off. When the high voltage is on, the contact will be closed.
>
> A setpoint contact closure provided. When the pump current goes below a preset limit, the setpoint contact closure will close.
>
> A normally closed contact will indicate that operating status of the pump. If there is a fault, then the contact closure will open.

A logarithmic analog output voltage that is proportional to the pump current will be provided.

RF Window Turbomolecular Pump Specification

1.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the turbomolecular pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

2.0 Turbomolecular pump

2.1 Pump Performance

The turbomolecular pump shall have a pump speed of at least 65 liters/second for nitrogen and 45 liters/second for hydrogen. The turbomolecular pump shall have a compression ratio of at least $5x10^8$ for nitrogen and $1x10^4$ for hydrogen. The turbomolecular pump shall have a throughput of at least 10 liters/second when the pressure at the inlet to the pump is 75 milliTorr for nitrogen. The turbomolecular pump shall have a base pressure of $2x10^{-10}$ Torr when the foreline pressure is below 7.5 milliTorr.

2.2 Physical Specifications

The turbomolecular pump shall have a 4.5 inch "conflat" flange on its inlet port. The turbomolecular pump shall be able to operate in any orientation.

The bearings shall be lubricated with an ultra-low vapor pressure solid lubricant to prevent bearing lubricant hydrocarbons from backstreaming into the vacuum system.

The turbomolecular pump shall have forced air cooling. Water cooling is not acceptable.

2.3 Pump Reliability

The turbomolecular pump should have ceramic bearings for long life. The nominal Mean Time To Failure shall be at least 80,000 hours.

3.0 Turbomolecular pump controller

It is highly recommended that the turbomolecular pump controller be mircorprocessor based. The pump controller shall provide self-diagnostics and protection from accidental air vent, pump over-temperature or over-current.

The pump controller shall be able to operate the turbomolecular pump from distances up to 250 feet away.

The pump controller shall have an alphanumeric display on the front panel to indicate pump status and display error messages.

The pump controller shall operate on 120 VAC at 60 Hz and be CE and/or UL approved.

3.1 Remote Control Interface

The pump controller shall have a remote control interface that can start and stop the pump by a remote contact closures. When the contact is closed the pump will start and when the contact opens the pump will stop.

The pump controller shall have +24VDC outputs that indicate the status of the turbo pump. One output will indicate the turbomolecular pump is in the startup mode. During startup, the +24 VDC will be present on the output and will return back to 0 VDC once the pump has reached normal operating speed. One output will indicate that the RPMs of the turbomolecular pump are higher than a programmable setpoint. One output will indicate if there is a fault condition in the turbomolecular pump or controller. The +24 VDC will be present on the output if there is a fault and will be 0 VDC if the pump and controller are operating correctly.

The various remote control signals discussed in sections 3.1 shall be available on panel mounted connectors on the rear of the controller. Separate connectors may be used for input and output functions.

RF Window Primary (Scroll) Pump Specification

1.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the scroll pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

2.0 Primary Pump

2.1 Pump Performance

The small primary pump shall be oil-free. The small primary pump shall have a pumping speed of 100 liters/minute while operating at 120 VAC and 60 Hz. The primary pump shall have an ultimate base pressure below 50 milliTorr.

2.2 Physical Specifications

The primary pump shall use a NW25 connection at the pump inlet with a protective screen. The connection at the outlet shall be a NW16.

The primary pump shall be equipped with an automatic isolation valve. An internal timer shall open the valve 10 seconds after the pump has been started. In the event of power loss or when the pump is switched off, the isolation valve shall close immediately.

The primary pump shall be equipped with an automatic gas ballast system to help flush out water vapor, other condensable gases and particulates. The gas ballast port shall have a standard pipe thread so that a dry nitrogen line may be attached if the ambient humidity is too high.

The primary pump shall be air cooled. Water cooling is not acceptable. The primary pump shall be able to operate in an ambient temperature range of +5° to +40° C.

The primary pump motor shall operate on 120 VAC at 60 Hz and be CE and/or UL approved.

2.3 Pump Reliability

The primary pump shall have teflon based tip seals for high reliability. When the base pressure is inadequate for backing the small turbo, the tip seals shall be easily field replaceable.

The mean time between maintenance shall be 9000 hours or more.

The primary pump motor shall automatic over-current and over-temperature protection.

RF Window Non Evaporable Getter (NEG) Pump Specification

1.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing the NEG pump shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

2.0 NEG pump

2.1 Pump Performance

The NEG pump will have a pump speed of at least 1000 liters/second for CO and 1300 liters/second for hydrogen. The NEG pump shall be constructed with sintered titanium-vanadium alloys and have a getter mass of at least 600 grams. The NEG pump shall have a capacity of at least 6000 Torr liters for hydrogen.

2.2 Physical Specifications

The NEG pump housing shall have a 4.5 inch "conflat" inlet flange. The pump housing shall have an internal heater for NEG activation or regeneration. The pump housing shall have an internal type "K" thermocouple to monitor the temperature during NEG activation or regeneration. The pump housing shall use ultra-high vacuum compatible electrical feedthroughs for the internal thermocouple and power for the heater.

2.3 Pump Reliability

Since NEG pumps are completely passive with no moving parts, there is no specification for Mean Time To Failure.

3.0 Activation/Regneration Power Supply/Controller

The NEG pump shall have a power supply/controller for activation/regeneration of the pump. The power supply/controller shall provide self-diagnostics and protection from pump heater over-temperature or over-current.

The pump controller shall be able to operate the NEG pump heater from distances up to 250 feet away.

The pump controller will have an alphanumeric display on the front panel to indicate pump activation or regeneration status and error messages.

The pump controller will operate on 120 VAC at 60 Hz and be CE and/or UL approved.

3.1 Remote Control Interface

The power supply/controller for activation/regeneration shall have a remote interface that can start and stop the heater power supply by a remote contact closures. When the contact is closed the power supply will be turned on and when the contact opens the power supply will be turned.

The power supply/controller shall accept a remote 0-20 milliAmpere analog signal for the activation/regeneration temperature setpoint. The activation/regeneration temperature shall be regulated to within $\pm 5^{\circ}$ C of the temperature requested by the remote analog setpoint input.

The power supply/controller shall provide a 4-20 milliAmpere analog output signal that represents the temperature read by the NEG pump housing internal thermocouple.

The power supply/controller will have a contact closure input, which will be used as an interlock. When an external contact is open, the power supply output to the NEG pump heater is disabled.

The power supply/controller will have contact closure outputs that indicate the status of the activation or regeneration. One output will indicate the NEG pump housing is over-temperature. One output will indicate the NEG pump housing internal heater is over-current. One output will indicate that the power supply output is disabled because the interlock is open.

The various remote control signals discussed in Section 3.1 will be available on panel mounted connections such as a terminal strip on the rear of the controller.

Vacuum Valve Specifications

1.0 Scope

The following valve specifications are based on the final DTL and CCL vacuum system designs. The valves employed by the DTL and CCL consist of two principle types, those physically located along the beamline to isolate the accelerator sections, and located off-axis to isolate pump components from the accelarator elements. Technical specifications for four types of valves are given here. Specifically, specifications are provided for DTL beamline valves, CCL beamline valves, RF window turbo pump isolation valves, and turbo cart isolation valves.

2.0 Mechanical specifications/requirements

All vacuum isolation valves will utilize a gate design for sealing. Each component isolation valve may have a preferential installation orientation to minimize leak rates from the high pressure side to the vacuum side. If so, this orientation will be clearly marked on the valve body.

With the exception of the beam line valves, the same types of RF window turbo pump isolation valves and turbo cart isolation valves shall be used on both the CCL modules and the DTL tanks. The valve space constraints, material requirements, and methods of connection, are discussed below.

2.1 Valve space constraints

The valve space constraints are based on the support structure geometry, the valve port locations, and vacuum system geometry. (List valve space constraints and show figures here) The limiting valve space envelopes are summarized in Table 1.

2.2 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing of the valves shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00). The valves shall have a body formed from stainless steel (turbo isolation and CCL beamline) or aluminum (DTL beamline) and may contain either metal or polymer (Viton, Neoprene, or Buna are acceptable) seals for the valve seat and valve body connections.

The design feature requirements for the valves are given in Table 1. These features are driven by the design of the vacuum systems and RF structures.

Table 1. Design features/requirements for the DTL and CCL vacuum system isolation valves.

Valve Type	Body Connection Type & Seal	Gate Seal	Limiting Space Envelope (H*W*T)(in*in*in)	Valve Power Failure Position	Representative Vendor/ Catalog #
DTL Beam Line	Insertable with Viton O-rings between DIN flanges	Viton O-ring	12*6*1.6	Closed	VAT / 08234-FA44
CCL Beam Line	Welded connections to beam tube	Viton O-ring	14*5*2	Closed	MDC / 303010-01-03 (or similar with weld connections rather than conflat flanges)
RF Window Turbo Isolation	4.5" Conflat flanges	Viton O-ring	14*5*4	Closed	MDC / 303002-01-03
Turbo Cart Isolation	8" Conflat flanges	Viton O-ring	24*10*6	Closed	MDC / 303006—01-03

3.0 Valve Operation

All valves shall be electropneumatic in their operation, capable of functioning from a 125 psig pressurized air source. Each valve will give an output signal by way of a contact closure to indicate the position of the valve. The electrical power requirements of all valves will be 24 VDC.

The beam line and turbo pump isolation valves shall fail in the closed position in the event of a power failure.

Specification for Convection Gauge, Cold Cathode Gauge and Gauge Controller

1.0 Scope

The following specifications are based on the current (1/8/01) vacuum system design for the CCL modules and DTL tanks for the SNS normal conducting linac.

2.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing of the vacuum gauges shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

3.0 Low vacuum gauge

The low vacuum gauge will measure the vacuum pressure by a combination of thermal conductivity and convection. The measurement range of the low vacuum gauge will be from 1000 Torr to 1×10^{-3} Torr, calibrated for nitrogen. The accuracy of the gauge must be at least $\pm$20%. The low vacuum gauge will be available with either a 2.75 inch conflat flange or a 1.33 inch mini-conflat flange.

4.0 High vacuum gauge

The high vacuum gauge will be an inverted magnetron cold cathode ion gauge. . The high vacuum gauge will have a 2.75" conflat flange. The measurement range of the high vacuum gauge will be from 1×10^{-3} Torr to 1×10^{-11} Torr, calibrated for nitrogen. The accuracy of the gauge must be at least $\pm$50%. The connector shall be a locking type high voltage connector such as SHV.

5.0 Vacuum gauge controller

The gauge controller will be able to read at least two low vacuum and two high vacuum gauges simultaneously and will have a local digital display where al least one low vacuum and one high vacuum gauge pressures are shown.

The gauge controller shall have a user accessible adjustment for each low vacuum gauge. There will be an adjustment for the maximum scale reading (atmoshpere) and the minimunm scale reading (less than 1×10^{-4} Torr).

The gauge controller will have an adjustable setpoint for the pressure of each gauge. The setpoint will have a normally open contact that will close when the pressure goes below the setpoint. The rating of the contact must be at least 30 vdc and 50 milliamps.

The gauge controller will have an analog output for each gauge. The analog outputs will be proportional to the pressure that each gauge is reading.

The controller will have +24VDC outputs that indicate the status of the high voltage for the high vacuum gauges.

The gauge controller will have a RS-485 serial communication port. The serial port shall communicate at a rate of at least 9600 baud. The serial port shall provide the latest pressure readings from all the gauges and access to all parameters that are available on the front panel.

Specification for Residual Gas Analyzer

1.0 Scope

The following specifications are based on the current (1/8/01) vacuum system design for the CCL modules and DTL tanks for the SNS normal conducting linac. The residual gas analyzer (RGA) shall consist of a sensor unit, electronics control unit and the appropriate software to program the RGA and read its data.

2.0 Parts, Materials and Processes

The parts, materials and processes used in the manufacturing of the sensor unit of the RGA shall be compatible for use in an ultra high vacuum system. See Spallation Neutron Source Accelerator Systems Division Vacuum Standards Handbook (SNS 102020000-ST0001-R00).

3.0 Sensor Unit

The sensor unit will measure the partial pressure of gases of the vacuum system from 1 to 100 Atomic Mass Units (AMU). The maximum operating pressure of the sensor unit shall be at least 1×10^{-4} Torr.

The minimum detectable partial pressure shall be 5×10^{-11} Torr. The minimum sensitivity of the detector shall be at least 2×10^{-4} Amps/Torr. The resolution shall be greater than 0.5 AMU at 10% peak height per American Vacuum Society (AVS) standard 2.3.

The sensor unit shall be mounted on a 2.75 inch conflat flange.

4.0 Electronics Control Unit

The electronics control unit shall contain all the necessary electronics to control the sensor unit and shall have the ability to be mounted remotely (approximately 100 ft) from the sensor unit. The electronics control unit shall be able to read the data from the sensor unit and process the data. The electronics control unit will monitor the status of the sensor unit and shut down the sensor if over-pressurized or if there is an error condition

The electronics control unit shall have a RS-232 serial communication port. The serial port shall communicate at a rate of at least 9600 baud. The serial port shall provide the latest partial pressure data that the electronics control unit has processed from the sensor unit. The serial port shall provide access to all the necessary programmable parameters of the sensor unit and provide up to date diagnostic information on the sensor unit and electronics control unit.

5.0 Software

The RGA shall be supplied with software that is compatible with Microsoft Windows NT version 4.0. The RGA software will communicate with the electronics control unit and provide an application environment to program all the necessary RGA parameters and read, display and store the RGA data. The RGA software will also read the sensor and electronics control unit diagnostics and inform the user of any problems.

The source code for the RGA software will be provided. SNS will port some sections of this code to run under EPICS.

18.0 Appendix F – Technical Note: Scroll Pump vs. Dry Piston Pump Operation

Applied Research Engineering Division
Accelerator Technologies Engineering Group

LLNL-ATEG-00-205
January 24, 2000

Technical Note: Scroll Pump vs. Dry Piston Pump Operation

Keith Kishiyama, Electrical Engineer, ATEG/LLNL

1.0 Pump specifications

The Varian Dry Scroll pump utilizes an orbiting scroll moving within a stationary scroll, forming crescent shaped pockets that progressively decrease in volume towards the center of the scrolls. As the volume decreases, gases are compressed and moved from inlet to exhaust. The seals on the vane tips of the orbiting scroll are PTFE-based and are oil-free. The scroll pump provides a very high pumping speed and a very good ultimate base pressure at reasonable cost. There are two models, one is rated at 20.5 cfm and the smaller one is rated at 10.6 cfm.

The VRC Dry Piston pump available through Kurt Lesker Co. operates with a high compression reciprocating piston that is also PTFE based with precision machined cylinder walls. There are two sizes in the standard models and two sizes in the soft start model. The standard models are rated at 28 cfm and 14 cfm. The soft start models offer programmable motor speed control. One feature of the soft start reduces the pumping speed in half when lower steady state gas loads are reached, thus extending the maintenance free period. The two soft start models are rated 10 cfm/5 cfm and 20 cfm/10 cfm.

A comparison of specifications from the vendor catalogs shows that in general, the scroll pump can reach a lower ultimate base pressure, but the single speed (standard) dry piston pump has greater pump speed. The soft start dry piston models operating at their normal speed have about the same pump speed as the scroll pumps. The catalog prices shows that the standard model 28 cfm dry piston costs 179% more than the 20.5 cfm scroll pump. The cost of a 20 cfm soft start dry piston is 193% more than the 20.5 cfm scroll pump. The standard 14 cfm dry piston costs 197% more than the 10.6 cfm scroll pump. The 10 cfm soft start dry piston costs 212% more than the10.6 cfm scroll pump.

One clarification of terminology must be made here; the statistics shown in both catalogs are not Mean Time Between Failure (MTBF). A more appropriate term should be Mean Time Between Maintenance (MTBM). The recommended maintenance schedule for the scroll pump is every 6,000 hours for a minor maintenance and 12,000 hours for a major maintenance. In general, LLNL has been performing only the major maintenance with very good reliability and performance from the pumps.

The standard speed dry piston states a maintenance free period of 10,000 hours. The soft start feature can extended the maintenance free period to between 25,000 to 30,000 hours depending on the vacuum system gas loads.

2.0 Pump operation

To obtain a "clean" vacuum system, it is absolutely essential that the pumps, valves and interlocks are correctly designed and operational procedures strictly followed. This discussion will focus on the apparent contamination of the forelines from backstreaming of condensed vapors and/or particulates from scroll pumps.

LLNL does not currently have any VRC dry piston pumps in operation and cannot comment directly on backstreaming from these pumps. However, it can be stated that any of these pumps if operated improperly, will backstream and that the VRC is not immune from this problem.

Since both these pumps are oil-free pumps, they do not have any fluids to flush out condensed vapors or accumulated particulates. Particulates will be generated as part of the normal operation of both pumps as the sealing surfaces move against each other. When backing a turbo at high vacuum, some natural flushing will occur in these pumps due to the throughput of gases pumped by the turbo. The amount of flushing obviously depends on the gas load that the turbo is pumping against.

VRC recommends a periodic purge of the dry piston pump to help flush out the condensed vapors and particulates. Older Varian scroll pumps were manufactured by Iwata Inc. and Varian also recommends a periodic purge for these pumps. Newer Varian Tri-scroll pumps have a gas ballast system near the center of the scrolls to automatically bleed air into the pump to help flush out the pump.

The particulates generated by the wear of the sealing surfaces in a scroll pump are not a problem under normal vacuum operations. The particulates generally do not migrate upstream against the decreasing volumes of the orbiting scroll. In the newer TriScroll pumps, the gas ballast system further reduces the probability of particulate migration by helping to flush particulates out of the pump and into the exhaust vent. In addition, the newer TriScroll pumps have a port available for a nitrogen purge in critical applications. In the older scroll pumps without the gas ballast or external periodic purge, the particulates will tend to accumulate in the pump near the exhaust port, but still can not backstream under normal vacuum operations as stated before. However, this accumulation could present a problem under abnormal vacuum conditions in a vacuum system without proper interlocks.

If the scroll pump is shut down by a power outage for example, but still remains open to the foreline, the vacuum in the foreline will cause backstreaming of the particulates into the foreline. Varian addresses this in a Product Information Bulletin #914S, "Isolation and Venting of TriScroll Pumps". Varian recommends an automatic isolation and venting valve (P/N VP25-120-50-60 for NW25) that isolates the scroll pump from the foreline during a loss of power and then vents the foreline at the inlet of the pump to prevent backstreaming.

3.0 LEDA Vacuum Systems Experience

There are four scroll pumps on the LEDA RFQ vacuum system. Two older model scroll pumps are used to regenerate the cryopumps and pump down the RFQ from atmosphere. Both operations are short term, high gas load operations and because of this high gas load, do not require a periodic purge and have never shown any contamination of the forelines.

The other two scroll pumps are the newer TriScroll pumps and back a total of six turbo pumps used for the regeneration of the NEGs on the RF windows. The turbos also operate full time to help pump the non-getterable gases in the RF window vacuum. The RF window vacuum system on the LEDA RFQ has been operational for over a year and there is no evidence of backstreaming of condensed vapors or particulates in the forelines of the RF window vacuum system.

The contamination in the LEDA power coupler test bed could have occurred during a period when the interlocks were disabled. It was observed that the interlocks were disabled on the power coupler test bed during one of the visits to LANL. Upon further investigation, it was found that one of the turbos had shut down due to an over temperature alarm. (It was later determined the turbo shutdown was due to a faulty bearing causing it to overheat.). It is unknown how long the interlocks had been disabled or how long the turbo had been shutdown. Also, during this time period the LEDA power coupler test bed had borrowed an older 610DS scroll pump since its TriScroll had been damaged due to a mis-wired electrical connection.

Since the interlocks were disabled, the gate valve that isolates the turbo from high vacuum did not close. Also, the foreline valve did not close and the still running scroll pump was then looking at high vacuum through the static turbo. This condition could have caused backstreaming of particulates and condensed vapors into the foreline. The worst case now would be to shutdown the vacuum system from this state, which would cause the high vacuum region to be vented to atmosphere through the stopped scroll pump. With the interlocks disabled, this condition could have occurred. This would most certainly guarantee backstreaming of particulates from the scroll pump.

4.0 Conclusion and recommendation

Both pumps if used properly in a properly designed vacuum system will provide for a "clean" vacuum system. In general, the roughing system should be designed with a foreline valve as close as practical to the pump to minimize the volume that will be vented when the pump is shut down. Proper interlocks are essential for the operation of a "clean" vacuum system. Interlocks should only be disabled by knowledgeable personnel who will be absolutely sure of the results. Any of these pumps (even the newer TriScroll) will backstream particulates and condensed vapors into the foreline if operated incorrectly.

The Mean Time Between Maintenance for the standard dry piston is roughly the same as the scroll pump. The additional cost of the soft start dry piston will extend the Mean Time Between Maintenance by a factor of 2.5 to 3.

The main factor in recommending a pump is to consider the requirements of vacuum system. For the SNS CCL, the scroll pumps will be used on carts to back turbos that will be used for the initial pumpdown of the linac and RF conditioning. Long term operation of the turbo cart will only be necessary in the very unusual failure mode where two ion pumps on a manifold are not operational since the CCL has redundant pumping for ion pumps. Therefore the Mean Time Between Maintenance is not the critical determining factor in which pump to recommend for the CCL.

The APT ED&D cryomodule vacuum system will utilize scroll pumps on turbo carts that will pump down the insulating vacuum. Once the insulating vacuum system is pumped down, then the cryomodule will be chilled down. When the cryomodule is cold, the turbo cart will removed since the system will cryopump itself. Because the scroll pump is not used for long term operation on the insulating vacuum the Mean Time Between Maintenance is not the critical determining factor.

The APT ED&D Cryomodule Power Coupler vacuum system will also use scroll pumps to back turbos. This design does call for continuous long-term operation of the scroll pump. However, to realize a reduced maintenance schedule over the scroll pump, a soft start dry piston pump would have to be specified. The initial purchase cost of the soft start dry piston pump is about twice the cost of a scroll pump, but does provide a Mean Time Between Maintenance that could be 2 to 2.5 times the scroll pump.

However, the cost of major maintenance for the scroll pump is approximately $1,400 for the 610DS scroll pump. The major maintenance kit is essentially a complete rebuilt pump head. There are five bolts that connect the head to the motor and it takes a technician 10 minutes to replace the head. The catalog price of the 610DS scroll pump is $8,250 and the catalog price of the cost of the 1201 soft start dry piston is $15,900. Therefore, the scroll pump must be operated at least five maintenance periods before the additional cost of the soft start dry piston pump is justified.

The maintenance period of the 610DS scroll pump is 12,000 hours, so five maintenance periods equals 60,000 hours. If we assume the maintenance period of the 1201 soft start dry piston pump is 30,000 hours, then the 610DS scroll pump can be operated for twice as long for the same cost as the 1201 soft start dry piston. The APT ED&D cryomodule program will be completed long before 30,000 operating hours are logged on the pumps, so it is doubtful whether the higher initial purchase cost of the soft start dry piston pump can be recovered during the life of the program.

Because the cost the scroll pumps are significantly less for comparable pump speed and ultimate base pressure, scroll pumps are still the recommended pumps.

19.0 Appendix G – Vacuum Handling and Cleaning Procedures

AW95-106130-00

MEL95-001817-00

SPECIFICATIONS

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE

TITLE	WRITTEN BY	DATE
Welding of Stainless Steel Components for Ultra-High Vacuum Environment	Michael R. McDaniel	9/1/95
	APPROVED-SPEC. & STDS. N/A	12/4/5
	APPROVED-DIVISION HEAD	9/4/5

1. SCOPE

1.1 Purpose This specification defines the procedures for controlling the quality of material to be used and the welds to be made on stainless steel components subject to Ultra-High Vacuum (UHV) environment for Lawrence Livermore National Laboratory (LLNL). Extreme care is required in the design fabrication and assembly of said components. This specification is applicable to the welding of austenitic, chromium-nickel steels (ASTM 300 series) using gas metal arc welding (GMAW) and/or gas tungsten arc welding (GTAW) processes. This is a general specification and not all sections necessarily apply to all drawings which refer to this specification. Refer to section 5.0 for required documentation for LLNL information and approval.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue used shall be the one in effect on the date of request for quotation. Any conflicts between this specification and the referenced documents shall be brought to the attention of LLNL in writing for resolution before any action is taken by the seller.

		CLASSIFICATION
REV. A BY	DATE	

SPECIFICATION

UNIVERSITY OF CALIFORNIA

LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE

TITLE	WRITTEN BY	DATE
Cleaning Copper and Copper alloys	C.P. Steffani	9-1-1993
	CHECKED BY J. W. Dini	9-1-1993
	APPROVED BY J.C. Whitehead	9-1-1993

SEQUENCE

1. Remove all tape, inks, and other residue using Acetone and a clean cotton rag or paper wiper. Other solvents may be used as long as they are permitted for use in the shop and the requester is aware of the change.

2. Pressure wash using RELEASE D'GREASE @ 10 vol. % and 3-5 KSI setting.
*** FOR FRAGILE PARTS IMMERSE IN ACETONE OR BRULIN 815GD. For components having tubes, blind holes, and passageways cleaning/rinsing agents will be fed into these areas at low pressure.**

3. Spray water rinse.

4. Immerse in ENTHONE NS-35 non-silicated cleaner (30 gm/L @ 65 C) for a minimum of 10 minutes.

5. Spray water rinse until all traces of cleaner are removed. If water breaks are present repeat step 4.

6. Descale in 50 % vol. HCL.

7. Spray water rinse.

8. Acid dip in ENTHONE ACTANE 97 (10 gm/L "A", 12 gm/L "B" @ 25 C) until surface is clean and bright.

SPECIFICATION

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE

TITLE	WRITTEN BY	DATE
Cleaning Stainless Steel Alloy Components	C.P. Steffani	9-1-1993
	CHECKED BY J. W. Dini	9-1-1993
	APPROVED BY J.C. Whitehead	9-1-1993

SEQUENCE

1. Remove all tape, inks, and other residue using Acetone and a clean cotton rag or paper wiper. Other solvents may be used as long as they are permitted for use in the shop and the requester is aware of the change.

2. Pressure wash* using RELEASE D'GREASE @ 10 vol. % and 3-5 KSI setting.
*** FOR FRAGILE PARTS IMMERSE IN ACETONE OR BRULIN 815GD. For components having tubes, blind holes, and passageways cleaning/rinsing agents will be fed into these areas at low pressure.**

3. Immerse in ENTHONE NS-35 non-silicated cleaner (30 gm/L @ 65 C) for a minimum of 10 minutes.

4. Spray water rinse until all traces of cleaner are removed. If water breaks are present repeat step 2.

5. Acid pickle (50 % vol. HNO_3 = 5 % vol. HF @ 25C) for:
   A. 10 minutes or until all mill scale is removed.
   B. 30 seconds to remove all traces of alkaline film.

6. Spray water rinse. All but welds and blind holes should be given special attention to remove all traces of trapped chemicals. The air water aspirator can be used to help rinse these hard places. Ultrasonic rinsing in DI water can also remove trapped material.

7. Cold water rinse. ($2x10^6$ ohm resistivity). Resistivity is monitored and maintained by automatic additions of fresh DI water.

AAW95-106131-00

MEL95-001818-00

SPECIFICATIONS

UNIVERSITY OF CALIFORNIA
LAWRENCE LIVERMORE NATIONAL LABORATORY

MECHANICAL ENGINEERING DEPARTMENT, LIVERMORE

TITLE	WRITTEN BY	DATE
Fabrication and Handling of Components for Ultra-High Vacuum Environment	Michael R. McDaniel	9/1/95
	APPROVED-SPEC. & STDS. N/A	12/95
	APPROVED-DIVISION HEAD	9/1/95

1. SCOPE

1.1 Purpose This specification defines the procedures for controlling the cleaning and handling of material and components subject to Ultra-High Vacuum (UHV) environment for Lawrence Livermore National Laboratory (LLNL). Extreme care is required in obtaining clean components that will not produce contamination at the end use machine. This specification will cover machining and cleaning techniques required before, during and after fabrication of said components. This is a general specification and not all sections necessarily apply to all drawings which refer to this specification. Refer to section 5.0 for required documentation for LLNL information and approval.

2. REFERENCE DOCUMENTS

The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated, the issue used shall be the one in effect on the date of request for quotation. Any conflicts between this specification and the referenced documents shall be brought to the attention of LLNL in writing for resolution before any action is taken by the seller.

			CLASSIFICATION
REV. A	BY	DATE	

20.0 Appendix H – Vacuum Seal Lists for CCL Modules 2 - 4

		CCL - Module 2						
		Design of seals and penetrations						
	Seal	**Seal**	**Seal**	**Seal Size in inches**		**Seal Size in cm**		
Locations	**Type**	**Quantities**	**Material**	**OD**	**Thick**	**OD**	**Thick**	
Coupling Cavities	C	18	Cu	7.33	0.124	18.62	0.31	
Power Coupling Cavities	C	4	Cu	7.33	0.124	18.62	0.31	
Beam Tubes	C	24	Al	2.265	0.134	5.75	0.34	
RF Window Waveguide	O	2	Al	9.63	0.125	24.46	0.32	
RF Window NEG pump	Conflat	4	Cu	5.8	0.25	14.73	0.64	
RF Window Turbo/Gate Valve	Conflat	2	Cu	1.375	0.125	3.49	0.32	
RF Window Ion Gauge	Conflat	2	Cu	1.375	0.125	3.49	0.32	
Beam Boxes, ends	O	4	Viton	5.625	0.125	14.29	0.32	
Beam Boxes, Diagnostics	O	2	Viton	2.875	0.125	7.30	0.32	
							Total	
				Leak	**Outgas**	**Leak**	**Outgas and**	
	Seals have	**Surface area**	**Outgas rate**	**Rate**	**Load**	**Load**	**Leak Load**	
Locations	**a 0.5 multipler**	**in cm^2**	**Torr-l/sec-cm^2**	**Torr-l/sec-mm**	**Torr-l/sec**	**Torr-l/sec**	**Torr-l/s**	
Coupling Cavities	0.5	28.94	5.00E-10	3.70E-10	2.60E-07	3.895E-06	4.156E-06	
Power Coupling Cavities	0.5	28.94	5.00E-10	3.70E-10	5.79E-08	8.657E-07	9.235E-07	
Beam Tubes	0.5	9.66	6.00E-10	3.70E-10	1.39E-07	1.605E-06	1.744E-06	
RF Window Waveguide	0.5	38.32	6.00E-10	2.00E-08	4.60E-08	3.074E-05		3.078E-05
RF Window NEG pump	0.5	46.16	5.00E-10	0	9.23E-08	0.000E+00		9.233E-08
RF Window Turbo/Gate Valve	0.5	5.47	5.00E-10	0	5.47E-09	0.000E+00		5.472E-09
RF Window Ion Gauge	0.5	5.47	5.00E-10	0	5.47E-09	0.000E+00		5.472E-09
Beam Boxes, ends	0.5	22.39	1.14E-08	1.04E-10	1.02E-06	1.867E-07	1.208E-06	**3.089E-05**
Beam Boxes, Diagnostics	0.5	11.44	1.14E-08	1.04E-10	2.61E-07	4.772E-08	3.086E-07	
							8.340E-06	
Diagnostic	**Quantities**							
Wire Scanner	2						4.08E-07	
Faraday Cup	0						0.00E+00	
Beam Position Monitor	4						6.52E-08	
							4.73E-07	

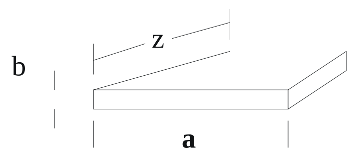
		CCL - Module 3						
		Design of seals and penetrations						
	Seal	**Seal**	**Seal**	**Seal Size in inches**		**Seal Size in cm**		
Locations	**Type**	**Quantities**	**Material**	**OD**	**Thick**	**OD**	**Thick**	
Coupling Cavities	C	18	Cu	7.33	0.124	18.62	0.31	
Power Coupling Cavities	C	4	Cu	7.33	0.124	18.62	0.31	
Beam Tubes	C	24	Al	2.265	0.134	5.75	0.34	
RF Window Waveguide	O	2	Al	9.63	0.125	24.46	0.32	
RF Window NEG pump	Conflat	4	Cu	5.8	0.25	14.73	0.64	
RF Window Turbo/Gate Valve	Conflat	2	Cu	1.375	0.125	3.49	0.32	
RF Window Ion Gauge	Conflat	2	Cu	1.375	0.125	3.49	0.32	
Beam Boxes, ends	O	6	Viton	5.625	0.125	14.29	0.32	
Beam Boxes, Diagnostics	O	3	Viton	2.875	0.125	7.30	0.32	
							Total	
				Leak	**Outgas**	**Leak**	**Outgas and**	
	Seals have	**Surface area**	**Outgas rate**	**Rate**	**Load**	**Load**	**Leak Load**	
Locations	**a 0.5 multipler**	**in cm^2**	**Torr-l/sec-cm^2**	**Torr-l/sec-mm**	**Torr-l/sec**	**Torr-l/sec**	**Torr-l/s**	
Coupling Cavities	0.5	28.94	5.00E-10	3.70E-10	2.60E-07	3.895E-06	4.156E-06	
Power Coupling Cavities	0.5	28.94	5.00E-10	3.70E-10	5.79E-08	8.657E-07	9.235E-07	
Beam Tubes	0.5	9.66	6.00E-10	3.70E-10	1.39E-07	1.605E-06	1.744E-06	
RF Window Waveguide	0.5	38.32	6.00E-10	2.00E-08	4.60E-08	3.074E-05		3.078E-05
RF Window NEG pump	0.5	46.16	5.00E-10	0	9.23E-08	0.000E+00		9.233E-08
RF Window Turbo/Gate Valve	0.5	5.47	5.00E-10	0	5.47E-09	0.000E+00		5.472E-09
RF Window Ion Gauge	0.5	5.47	5.00E-10	0	5.47E-09	0.000E+00		5.472E-09
Beam Boxes, ends	0.5	22.39	1.14E-08	1.04E-10	1.53E-06	2.801E-07	1.811E-06	**3.089E-05**
Beam Boxes, Diagnostics	0.5	11.44	1.14E-08	1.04E-10	3.91E-07	7.158E-08	4.629E-07	
							9.10E-06	
Diagnostic	**Quantities**							
Wire Scanner	2						4.08E-07	
Faraday Cup	1						2.50E-07	
Beam Position Monitor	4						6.52E-08	
							7.23E-07	
						Total Through-put without RF vac sys =	**9.82E-06**	

		CCL - Module 4						
		Design of seals and penetrations						
	Seal	**Seal**	**Seal**	**Seal Size in inches**		**Seal Size in cm**		
Locations	**Type**	**Quantities**	**Material**	**OD**	**Thick**	**OD**	**Thick**	
Coupling Cavities	"C"	18	Cu	7.33	0.124	18.62	0.31	
Power Coupling Cavities	"C"	4	Cu	7.33	0.124	18.62	0.31	
Beam Tubes	"C"	24	Al	2.265	0.134	5.75	0.34	
RF Window Waveguide	"O"	2	Al	9.63	0.125	24.46	0.32	
RF Window NEG pump	Conflat	4	Cu	5.8	0.25	14.73	0.64	
RF Window Turbo/Gate Valve	Conflat	2	Cu	1.375	0.125	3.49	0.32	
RF Window Ion Gauge	Conflat	2	Cu	1.375	0.125	3.49	0.32	
Beam Boxes, ends	"O"	4	Viton	5.625	0.125	14.29	0.32	
Beam Boxes, Diagnostics	"O"	2	Viton	2.875	0.125	7.30	0.32	
							Total	
				Leak	**Outgas**	**Leak**	**Outgas and**	
	Seals have	**Surface area**	**Outgas rate**	**Rate**	**Load**	**Load**	**Leak Load**	
Locations	**a 0.5 multipler**	**in cm^2**	**Torr-l/sec-cm^2**	**Torr-l/sec-mm**	**Torr-l/sec**	**Torr-l/sec**	**Torr-l/s**	
Coupling Cavities	0.5	28.94	5.00E-10	3.70E-10	2.60E-07	3.90E-06	4.16E-06	
Power Coupling Cavities	0.5	28.94	5.00E-10	3.70E-10	5.79E-08	8.66E-07	9.24E-07	
Beam Tubes	0.5	9.66	6.00E-10	3.70E-10	1.39E-07	1.60E-06	1.74E-06	
RF Window Waveguide	0.5	38.32	6.00E-10	2.00E-08	4.60E-08	3.07E-05		3.08E-05
RF Window NEG pump	0.5	46.16	5.00E-10	0	9.23E-08	0.00E+00		9.23E-08
RF Window Turbo/Gate Valve	0.5	5.47	5.00E-10	0	5.47E-09	0.00E+00		5.47E-09
RF Window Ion Gauge	0.5	5.47	5.00E-10	0	5.47E-09	0.00E+00		5.47E-09
Beam Boxes, ends	0.5	22.39	1.14E-08	1.04E-10	1.02E-06	1.87E-07	1.21E-06	**3.09E-05**
Beam Boxes, Diagnostics	0.5	11.44	1.14E-08	1.04E-10	2.61E-07	4.77E-08	3.09E-07	
							8.34E-06	
Diagnostic	**Quantities**							
Wire Scanner	2						4.08E-07	
Faraday Cup	0						0.00E+00	
Beam Position Monitor	4						6.52E-08	
							4.73E-07	
						Total Through-put without RF vac sys =	**8.81E-06**	

21.0 Appendix I – Vacuum Engineering Calculation Sheets

RF Attenuation for the CCL Window Vacuum Pump System

Calculate the RF field attenuation in the rectangular grill slots This will be treated as a rectangular wave guide below cut-off.. The grill is made up of various length slots, but the longest slot lets the most energy through, so that is the one that will be modeled as the worst case. The slot dimensions are shown below and represent a rectangular waveguide



Field strength attenuates as $\quad E := E_0 \cdot e^{-\alpha z}$

The essential grill dimensions in cm are:

$$a := 1.43\,2.54$$

$$z := 0.23\,2.54$$

For the dominate TE10 mode in a rectangular waveguide, the cut-off wavelengthλc, is:

$$\lambda_c := 2 \cdot a \qquad \lambda_c = 7.264 \quad \text{cm}$$

Calculate the wave length of the RF power in the waveguide in cm

$$\lambda := \frac{\left(3 \cdot 10^{10}\right)}{805\,10^{6}} \qquad \lambda = 37.267 \quad \text{cm}$$

$\varepsilon_1 := 1.0$ for air

The attenuation through the grill is:

$$\alpha_g := \left[8.69 \sqrt{\left(2 \cdot \frac{\pi}{\lambda_c}\right)^2 - \varepsilon_1 \cdot \left(2 \cdot \frac{\pi}{\lambda}\right)^2} \right] \cdot z$$

T. Morino, "Microwave Transmission Design Data", equation 8-21, page 140

$$\alpha_g = 4.307 \quad \text{db}$$

Attenuation in the first pipe (nipple) section, which is the smallest of the 2 pipes

$$D_s := 4.5 \cdot 2.54$$

$$L_s := 5.085 \cdot 2.54$$

The dominate mode in a circular waveguide is TE11 and the attenuation formula for that mode is, where αsc stands for attenuation, small, circular :

$$\alpha_{sc} := \left[8.69 \cdot \sqrt{\left(\frac{1.841}{\frac{D_s}{2}} \right)^2 - \left[\frac{(2 \cdot \pi)}{\lambda} \right]^2} \right] \cdot L_s$$

T. Morino, "Microwave Transmission Design Data", equation 7-38, page 120

$$\alpha_{sc} = 30.809 \quad \text{db}$$

Attenuation in the larger nipple, or pipe is:

$$D_l := 5 \cdot 2.54$$

$$L_l := 6.845 \cdot 2.54$$

$$\alpha_{lc} := \left[8.69 \cdot \sqrt{\left(\frac{1.841}{\frac{D_l}{2}} \right)^2 - \left[\frac{(2 \cdot \pi)}{\lambda} \right]^2} \right] \cdot L_l$$

$$\alpha_{lc} = 35.635 \quad \text{db}$$

The total attenuation, in db, for the vacuum system is:

$$\alpha\_total := \alpha_g + \alpha_{sc} + \alpha_{lc}$$

$$\alpha\_total = 70.750 \qquad \text{db}$$

This gives the following power levels at the beginning of the NEG pump cartridge (closest to the window grill):

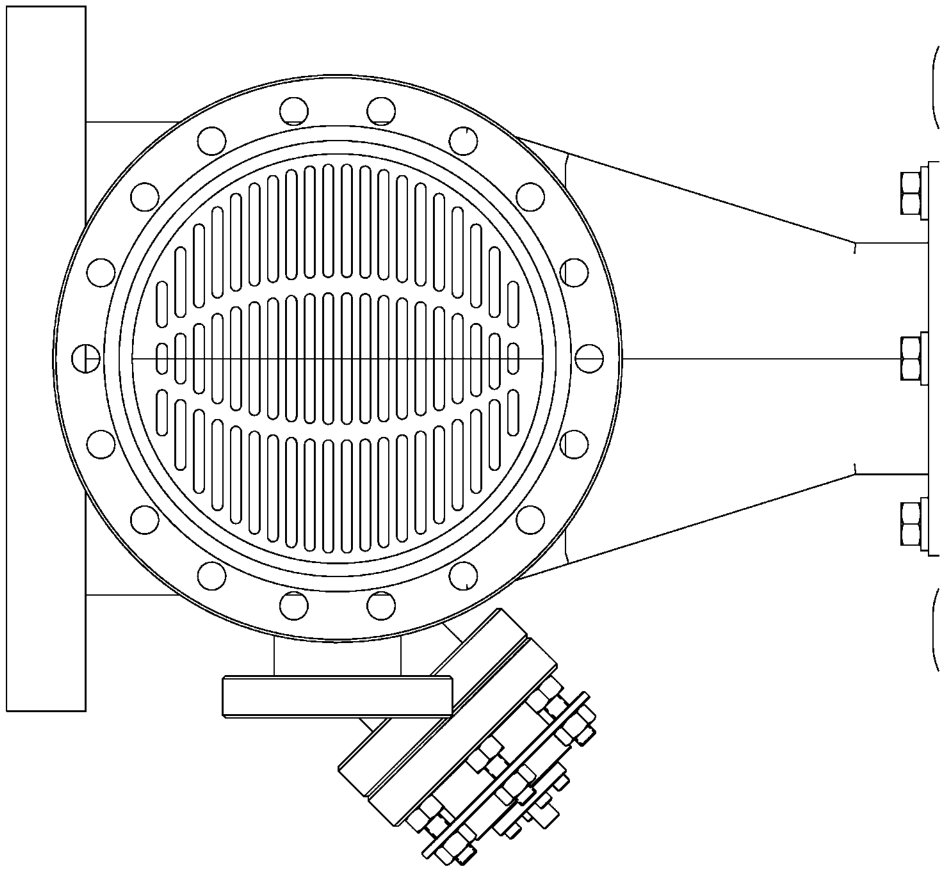
The peak RF power is 5 Mega Watts, but the duty factor is only 10%. So the average power is 500,000 watts. Calculate the power at the NEG Pump.

$$db := 10 \cdot \log\left(\frac{5 \cdot 10^5}{.042} \right)$$

$db = 70.757$ close enough

So the power that reaches the Ion Pump is ***42 milliwatts.***

CCL, R.F. Window Pump Out Port, Vacuum / R.F. Grill



This drawing is a top view picture of the R.F. grilled shield that protects the vacuum NEG pump from the R.F. energy in the Window wave guide.

CCL RF Window Vacuum Pumping Calculation

From John Bernardin's calculations, the total outgasing of the cavity is
The details of this particular calculation are not given in this paper.

using a WR975 wave guide:

$a1 := 330\ cm^2$ area of the window

$a2 := 2787 cm^2$ area of the waveguide

$$q1 := \left(5 \cdot 10^{-8}\right)$$
$$q2 := \left(1 \cdot 10^{-10}\right) \ torr - \frac{liter}{sec}$$

$$Q := \frac{(a1 \cdot q1 + a2 \cdot q2)}{ss\_pressure} \qquad ss\_pressure := 1 \cdot 10^{-7}\ torr$$ steady state pressure

$$Q = 167.787\ \frac{liter}{sec}$$

Assume the RF shield is a grilled slot with the following dimensions in cm.
The slot lengths vary because they are in a circle, but for this calcualtion they are averaged

$slot\_width := 0.3175$

$average\_slot\_length := 1.75$

$grill\_thick := 0.635$

$slots\_per\_grill := 60$

$$K_{slit} := \frac{slot\_width}{average\_slot\_length} \qquad K_{slit} = 0.181$$

Calculate the grill conductance using the formulas from the books "Roth" and "Vacuum Engineering Calulations." Both books use the same formula.

$$c\_grill\_roth := 30.9 \left(average\_slot\_length^2 \cdot slot\_width^2\right) \cdot \frac{1.444}{[(average\_slot\_length + slot\_width) \cdot grill\_thick]}$$

$$c\_grill\_roth = 10.492\ \frac{liters}{sec \cdot slot}$$

$$total\_c\_grill\_roth := (c\_grill\_roth) \cdot (slots\_per\_grill)$$

$$total\_c\_grill\_roth = 629.537\ \frac{liters}{sec}$$ Total conductance of the grill

Select a NEG pump size

$pump := 1370 \ \frac{liters}{sec}$ This pump size includes the turbo as well as the NEG pump.

Calculate the effective pumping speed from the vacuum RF grill to the pump.

The tube size of A in centermeters is:

$A\_diam := 11.43 \qquad A\_length := 14.82$

The conductance of tube A is:

$$con\_A := 12.12 \cdot \frac{A\_diam^3}{A\_length + \frac{4}{3} \cdot A\_diam} \qquad con\_A = 602.077 \ \frac{liters}{sec}$$

The tube size of B in centermeters is:

$B\_diam := 14.63 \qquad B\_length := 15.16$

The conductance of tube A is:

$$con\_B := 12.12 \cdot \frac{B\_diam^3}{B\_length + \frac{4}{3} \cdot B\_diam} \qquad con\_B = 1.095 \times 10^3 \ \frac{liters}{sec}$$

The total conductance is:

$$inverse\_Ctotal := \left(\frac{1}{con\_A}\right) + \left(\frac{1}{con\_B}\right) + \left(\frac{1}{total\_c\_grill\_roth}\right)$$

$$Ctotal := \frac{1}{inverse\_Ctotal}$$

$$Ctotal = 240.222 \ \frac{liters}{sec}$$

The effective pumping speed of the system is:

$$q\_effec := Ctotal \cdot \frac{pump}{(Ctotal + pump)}$$

$$q\_effec = 204.384 \quad \frac{liters}{sec}$$

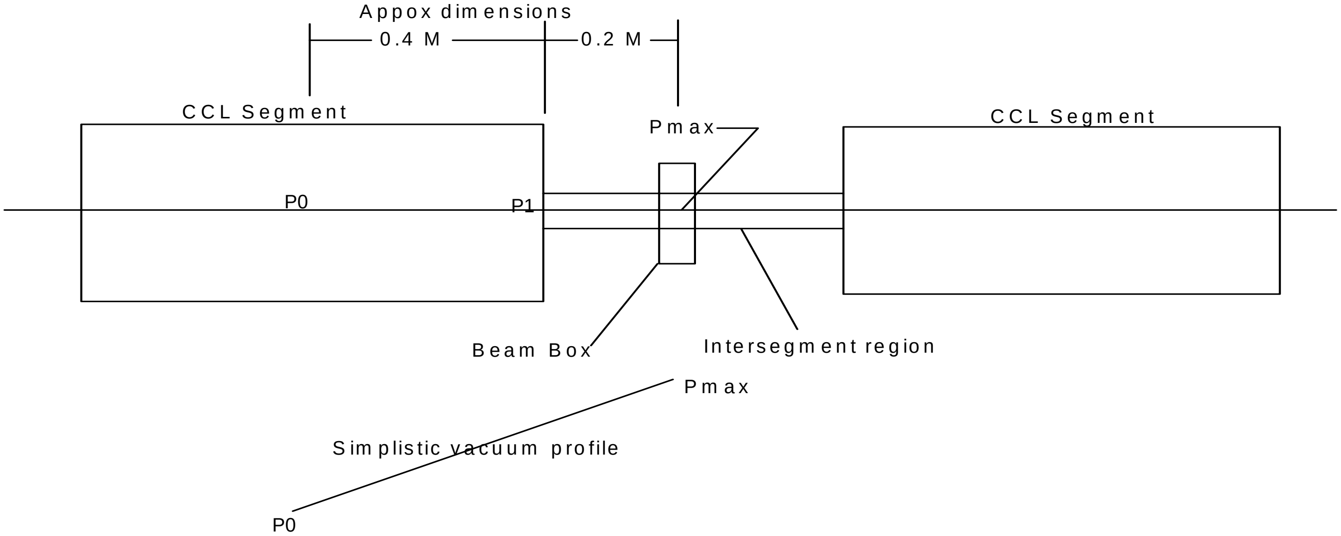
Check to see if this pumping speed will meet the pumping requirements of the system

$$pumping\_requirement := \frac{q\_effec}{Q}$$

$$pumping\_requirement = 1.218$$

A pumping requirement 1 or greater will meet the needs of this system.

Calculate the maximum permissible beam diagnostic outgas load in the CCL beam line



Inputs

$P_{strip} := 8.87 \cdot 10^{-8}$

Pstrip is the Maximum allowed vacuum pressure (torr) in the CCL beam line. See **"Beam Loss From H minus Stripping in Residual Gas, by Robert Shafer, 5/1/99, TN:LANSCE - 1:99-085"**. This requirement is only applicable for the last module; the other modules have a higher pressure. (see Design Criteria, page 23)

$P0 := 4.44 \cdot 10^{-8}$

P0 is a conservative peak pressure. It is expected that after several hundred hours of operation, the gas will consist mostly hydrogen which will have a pressure of 1.9E-8 torr. (see Preliminary Design Report II, page 16)

$bb\_id\_in := 5.625$

$bb\_len\_in := 3.375$

$beam\_tube\_id\_in := 1.25$

$seals\_leakage\_permeability := 1.38 \cdot 10^{-7} \frac{(Torr - liters)}{sec}$

$ss\_outgas := 1 \cdot 10^{-10} \frac{(torr - liters)}{sec \cdot cm^2}$

$cu\_outgas := 1 \cdot 10^{-10}\ torr \cdot \frac{liters}{sec \cdot cm^2}$

$inter\_seg\_length\_cm := 46$ Inter segment length at the end of module #4

Note, "bb" stands for beam box and "ss" stands for stainless steel.

$bb\_id\_cm := bb\_id\_in \cdot 2.54$ $bb\_id\_cm = 14.287$

$bb\_len\_cm := bb\_len\_in \cdot 2.54$ $bb\_len\_cm = 8.572$

$beam\_tube\_id\_cm := beam\_tube\_id\_in \cdot 2.54$

$temp := 296$ Degrees K

$M\_air := 28.98$ Molecular mass of air

I am only going to model the longest inter-segment beam line in the CCL which is Module #4. If the gas pressure is below the value where the electrons will be stripped off the beam, then all of the other inter-segments will also have a pressure less then what I will calculate in this calculation. In other words, this is a worst case situation. If the criteria is met here, then it is met everywhere in the CCL inter-segments.

$$bb\_surface := \pi\cdot(bb\_id\_cm)\cdot(bb\_len\_cm) + 2\frac{\left(\pi bb\_id\_cm^2\right)}{4} - 2\left(\pi\cdot\frac{beam\_tube\_id\_cm^2}{4}\right)$$

$$bb\_outgas\_load := bb\_surface\cdot ss\_outgas$$

$$bb\_outgas\_load = 6.896\times 10^{-8}\ torr\cdot\frac{liters}{sec}$$

Calculate the outgassing from the beam tube and then the total outgas load of the Inter segment, but not including any beam diagnostics in the beam box.

$$beamtube\_outgas\_load := \left[\pi\cdot(beam\_tube\_id\_cm)\cdot(inter\_seg\_length\_cm - bb\_len\_cm)\right]\cdot ss\_outgas$$

$$total\_outgas\_load := bb\_outgas\_load + beamtube\_outgas\_load + seals\_leakage\_permeability$$

$$total\_outgas\_load = 2.443\times 10^{-7}\ \frac{torr - (liters)}{sec}$$

The seal_leakage_permeability is an average number per inter-segment, see spreadsheet, (Vacuum CCL penetrations, outgas-loads.xls), Module 4. The only seals that were considered were the beam box seals. The other seals are made at the ends of the beam tube which are next to an accelerating structure.

I will model the Inter-segment by cutting the length of the beam line in half and assuming half of the total outgas load flows through the line. I will also assume the beam box is in the middle of the Inter-segment region. First I will find the conductance of half of the beam line.

$$pipe\_length := (inter\_seg\_length\_cm) - bb\_len\_cm$$

Determine whether this is a short tube conductance problem or a long tube. If the length is 20 times the diameter than it is considered a long tube.

$$\frac{\left(\frac{pipe\_length}{2}\right)}{beam\_tube\_id\_cm} = 5.894$$ This is considered a short tube

$$\left(\frac{\frac{pipe\_length}{2}}{\frac{beam\_tube\_id\_cm}{2}}\right) = 11.788$$ L /r ratio used in table 6.5, page 136

Molecular conductance of an aperture is:

$$area\_cm2 := \pi \frac{(beam\_tube\_id\_cm)^2}{4}$$ where (area_cm^2) is the area of the aperture

$$C_{ma} := 3.64 \sqrt{\frac{temp}{M\_air}} \cdot area\_cm2 \qquad C_{ma} = 92.103 \quad \frac{liters}{sec}$$

Molecular conductance of a short pipe. The Pr dimensionless ratio it taken from figure 6.5 on page 136, "Vacuum Engineering Calculations, Formula, and Solved Exercises".

$$Pr := 0.18$$

$$C_{mT} := C_{ma} \cdot Pr$$

$$C_{mT} = 16.579 \quad \frac{liters}{sec} \qquad P0 = 4.44 \times 10^{-8}$$

The maximum vacuum pressure that can be sustained without excessive beam stripping is Pstrip = 8.87E-8 torr. Setting Pstrip half way between P0 and Pmax, find Pmax

$$P_{strip} := \frac{1}{2}(Pmax + P0)$$

$$Pmax := 2 \cdot P_{strip} - P0$$

$$Pmax = 1.33 \times 10^{-7} \quad torr$$

Using the sketch at the top of the page, and the linear simplistic pressure profile, calculate the pressure at P1.

$$P1 := \frac{2}{3}(Pmax - P0) + P0$$ Equation 1

$$P1 = 1.035 \times 10^{-7} \quad torr$$

The relation between conductance "C", through put "Q" and pressure is: Q=(Pmax-P1)C. Equation 2

Substituting equation 1 into equation 2 and solving for Qtotal gives: (The reason for multiplying by 2 is because up to now, I have been analyzing half of the inter-segment region, but I need the Q of the full region.)

$$\mathrm{Qtotal} := 2 \cdot C_{mT} \cdot \left[\mathrm{Pmax} - \left(\frac{2}{3} \mathrm{Pmax} + \frac{1}{3} \mathrm{P0} \right) \right]$$

$$\mathrm{Qtotal} = 9.792 \times 10^{-7} \quad \frac{(\mathrm{torr} \cdot \mathrm{liters})}{\mathrm{sec}}$$

Then the maximum diagnostic outgas load that is allowed is:

$$\mathrm{q\_max\_diagnostic} := \mathrm{Qtotal} - \mathrm{total\_outgas\_load}$$

$$\mathrm{q\_max\_diagnostic} = 7.35 \times 10^{-7} \quad \frac{(\mathrm{torr} \cdot \mathrm{liters})}{\mathrm{sec}}$$

As a check, see if the Beam Tube Pressure is equal to Pmax.

$$\mathrm{beamtube\_press} := \frac{\left[\left(\frac{\mathrm{total\_outgas\_load} + \mathrm{q\_max\_diagnostic}}{2} \right) + \left(C_{mT} \right) \cdot (\mathrm{P1}) \right]}{C_{mT}}$$

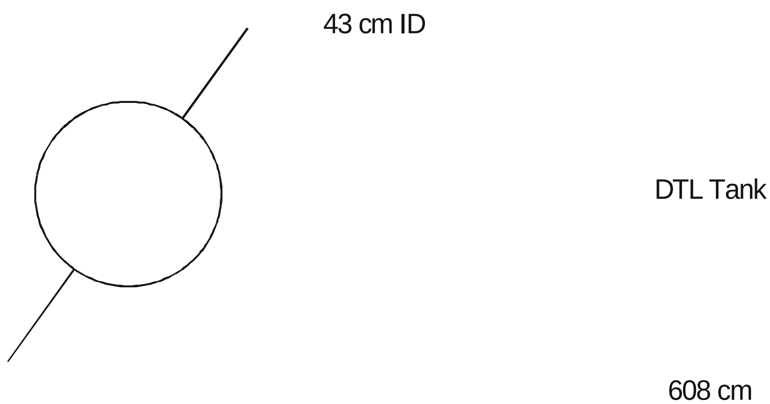
$$\mathrm{beamtube\_press} = 1.33 \times 10^{-7} \qquad \mathrm{Pmax} = 1.33 \times 10^{-7}$$

Calculate how much higher this pressure is then the pressure where excessive stripping occurs.

$$\mathrm{exceeds} := \frac{\mathrm{beamtube\_press}}{P_{strip}} \qquad \mathrm{exceeds} = 1.499$$

Bob Shafer feels that the stripping pressure can be exceeded by 2 to 3 times for short distances along the beam line. Bob's defination of short is about 5 meters, so the above figure looks good.

DTL tank back fill with dry N2 pressurization. Calculate the hole size in a Restrictive Flow Orifice Device to restrict the flow rate to a safe value. (Note, DTL tanks are isolated by vacuum valves in groups of 2.)



Using Roger Shrouf's Sandia National Laboratory's paper "Gas Flow Characterization of Restrictive Flow Orifices Devices" (SANDIA97-1670), a 0.020 inch diameter hole in the restrictive flow orifice in the gas line is needed to keep the flow rate to no greater than 13.5 scfm.

Restrictive Flow Orifice - Not to scale

Assumptions

Keep the gas back fill flow rate low to be sure the DTL tank isn't over pressurized. A CTI Cryogenics Pressure Relief Valve (PRV) or equivalent is used, with a 1 inch line. This PRV can stand a 13.5 scfm flow rate and not exceed 2 psi. Therefore, use the 13.5 scfm back fill flow rate.

A standard N2 gas bottle holds 220 standard cubic feet of gas and has a pressure of 2,000 to 2,200 psig. (I called the gas facility and got this information.)

Calculate the internal volume of the largest DTL tank

$$ID := 43\,cm$$

$$Length := 608\,cm$$

$$Volume := 2\left(\pi\cdot\frac{ID^2}{4}\right)\cdot Length$$ Volume of two tanks.

$$Volume = 62.361\,ft^3$$

$$P1 := 2200\cdot psi$$

$$V1 := 220\cdot ft^3$$

$$V2 := 220\cdot ft^3 - Volume$$

$$V2 = 157.639\,ft^3$$ Cubic feet of gas left in the nitrogen bottle after back filling 2 DTL tanks at once, which will be the general case.

Calculate the approximate pressure in a new N2 bottle after 2 DTL tanks are pressurized to, not greater then 2 psig. I am doing this to see what the average flow rate into the tanks will be after 2 DTL tanks are back filled with dry N2.

$$P2 := \left(\frac{V2}{V1}\right)\cdot P1$$

$$P2 = 1.576\times 10^3\,psi$$ At this pressure, the flow rate will average to about 11 scfm. However, if the gas bottle isn't refilled, it will take longer to back fill another set of DTL tanks.

$$Q_{ave} := 11\,\frac{ft^3}{min}$$

$$Back\_fill\_time := \frac{Volume}{Q_{ave}}$$

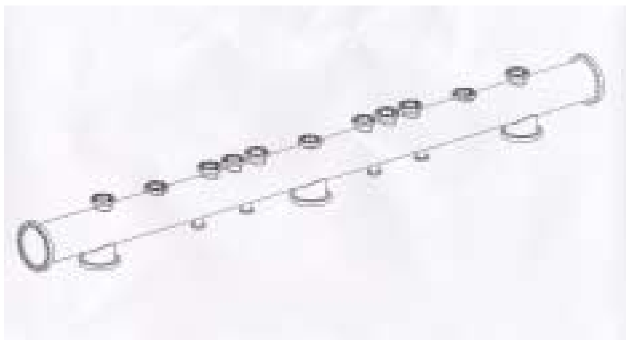
$$Back\_fill\_time = 5.669\,min$$

Los Alamos
NATIONAL LABORATORY
memorandum

Engineering Sciences & Applications
Design Engineering Group

To/MS: **Steve Ellis, H824**
From/MS: **Doug Kemp, H821**
Phone/FAX: *667-5752/667-3559*
Symbol: ESADE-00-
Date: **June 29th, 2000**

SUBJECT: SNS Hot Model Vacuum Manifold - Structural Stability



THE DESIGN (pre May 00) L.A.N.L. Part #153Y643961 is shown above and its specifications are: 8"outer diameter 304L stainless steel tube, 180" long. And the wall thickness is 0.065", or 1/16". There are eleven tees on the top of the manifold, each 3" in diameter and pulled with a special die. There are no ring stiffeners circling the tees. Three 150 pound ion pumps hang from equally spaced 6" diameter tees on the belly of the manifold. When the vessel is evacuated, the unequal atmospheric pressure (14.7 psi) pushes upward upon the manifold with a force of approximately 1150 pounds. A securement against these forces is provided by two steel clamps, restraining each end of the tube. Since the writing of this report, the wall thickness in the above vacuum vessel has been increased to 1/8", and its length has shrunk to 136".

In addition, it is worthy to note that the LANSCE CCL vacuum manifold is 8" in diameter, its wall thickness is 1/8" and its length varies between 55" and 80". (See the attached LAMPH drawing number 60Y-124676 D1) And there are eight tees equally spaced on the top side. Each tee is 1.75" in diameter. One ion pump hangs off of a 6" diameter tee. The LANSCE vacuum manifold has been operational for thirty years.

ROARK'S ELASTIC INSTABILITY CALCULATIONS Attached to this memo are three MathCAD spreadsheets. These self explanatory MathCAD spreadsheets are very important and I put more trust in them than in the Finite Element analyses shown later in this report. As seen in the MathCAD spreadsheets, Roark's formulas show that in the radial direction buckling occurs long before yielding. And in this buckling direction Roark's formulas seem to indicate that the critical atmospheric loading is 18 psi. In the axial direction, the vacuum vessel has much more strength. On the matter of elastic stability of shells, I obtained very good advice and help from Tom Butler of ESA Division, L.A.N.L.. He suggested an approximate and analytical method for determining the axial direction critical loading of our vacuum vessel. The idea is to find the maximum compressive stress within the vessel, and assume that this maximum compressive stress acts everywhere within the vessel. And then determine a critical axial buckling load. Using this scenario, in the axial direction, yielding occurs before buckling for a 0.065" wall thickness.

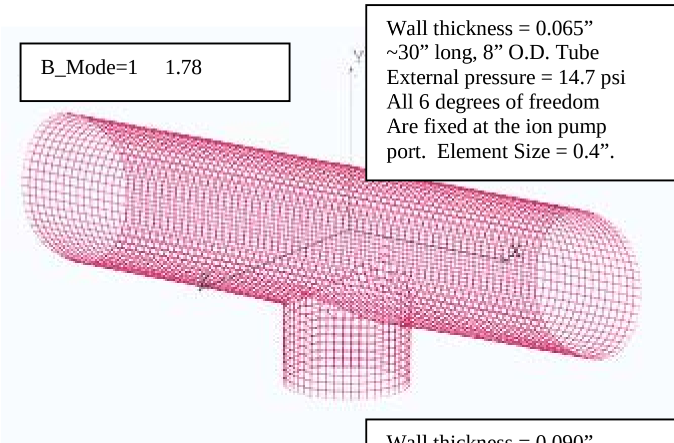
On the same MathCAD spreadsheet is a rough approximation to the Von Mises stress located at a point of high stress concentration, near the tees. And additionally there is a determination of the Maximum Allowable Working Pressure for the vessel according to the A.S.M.E Boiler and Pressure Vessel Code. This appears at the bottom of the spreadsheet. Notice that for the 0.065" thick walled vessel, the Maximum Allowable Working Pressure is approximately 11 psi.

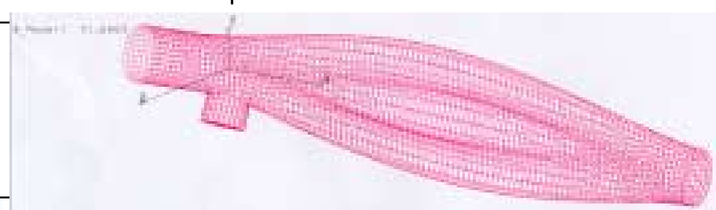
<u>FINITE ELEMENT ANALYSES</u> The "COSMOS" Finite Element Analysis software, made by the SRAC Corporation, was used to model the vacuum vessel. There are computer memory and speed limitations for exhaustive finite element modelling of this problem, regardless of the FEA platform used. To capture a small buckling wave, the average element size should be sufficiently small, maybe 1/4" square. And to accurately model all of the modes of buckling, the vacuum vessel must be modeled in its entirety. For example, for a thick shell element with 1/4" long sides, roughly 75 thousand elements are needed. The capacity to fully model such a system exceeds the capabilities of our computer. However, some of the buckling modes can still be found using larger shell elements, and even without the modelling of the entire vessel. Such were the intentions of our analyses.

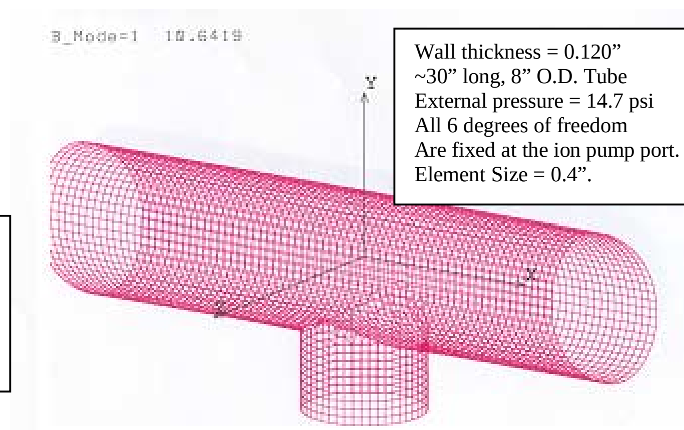
The COSMOS calculations shown below are deformed element grids, and the deformed shape represents a buckling mode. B_Mode=1 is a symbol denoting the multiplication factor. For example, the ambient pressure in these runs is 14.7 psi, and a B_Mode=1 of 1.79 implies that a pressure greater than or equal to 1.79*14.7psi will buckle or collapse the vessel.

B_Mode=1 1.78

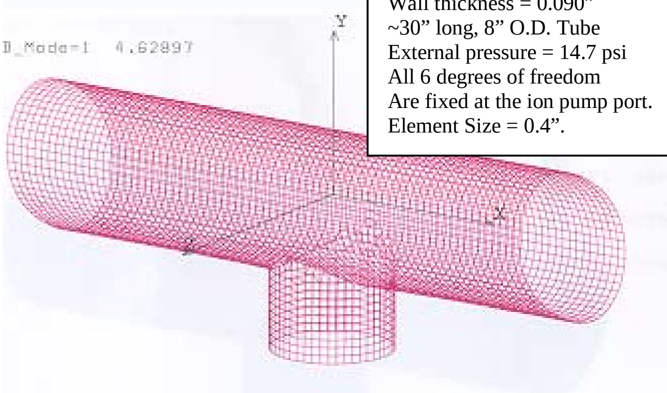
Wall thickness = 0.065"
~30" long, 8" O.D. Tube
External pressure = 14.7 psi
All 6 degrees of freedom
Are fixed at the ion pump
port. Element Size = 0.4".





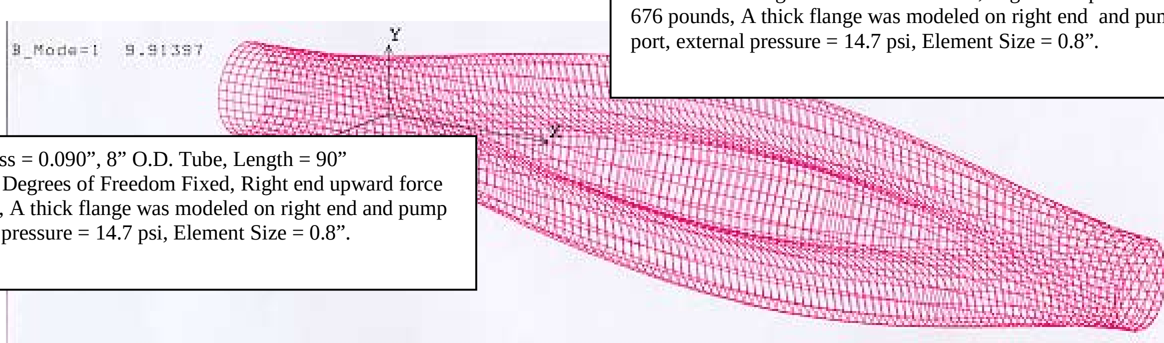


Wall thickness = 0.120"
~30" long, 8" O.D. Tube
External pressure = 14.7 psi
All 6 degrees of freedom
Are fixed at the ion pump port.
Element Size = 0.4".

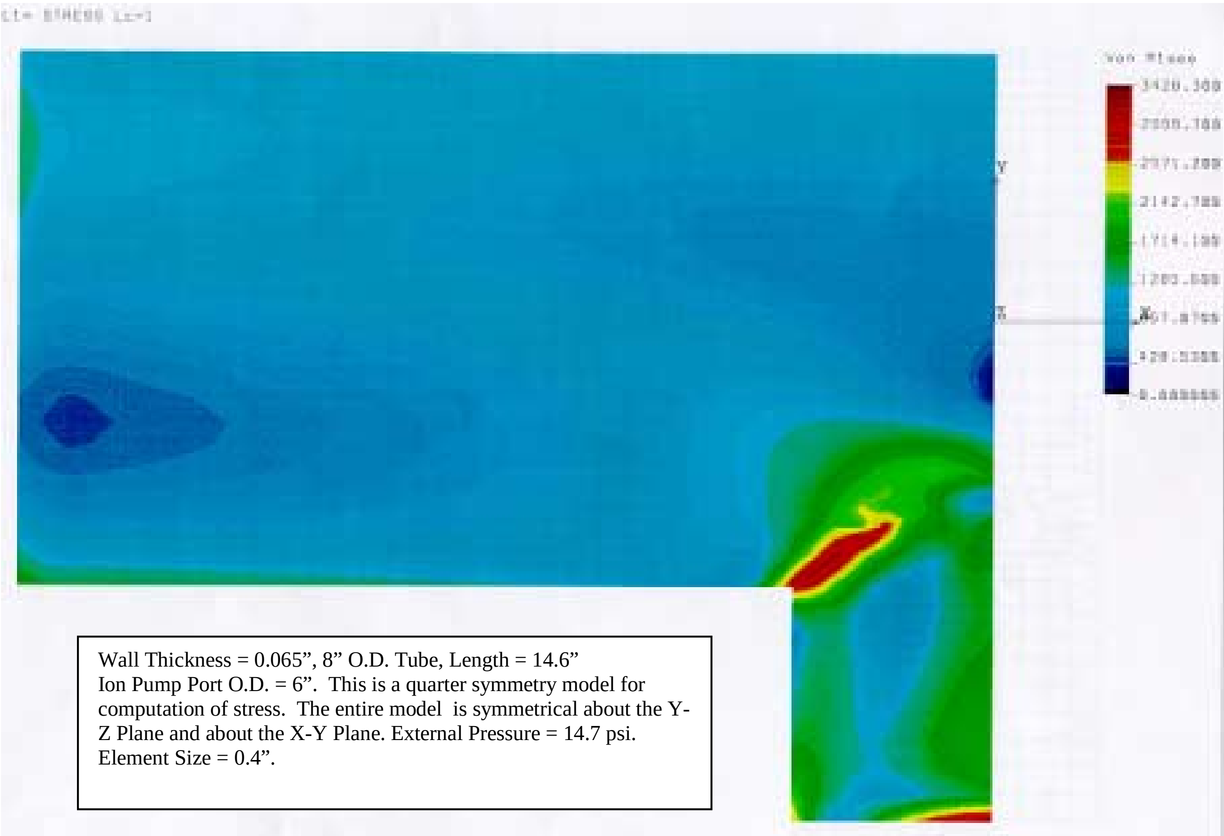


Wall thickness = 0.090"
~30" long, 8" O.D. Tube
External pressure = 14.7 psi
All 6 degrees of freedom
Are fixed at the ion pump port.
Element Size = 0.4".

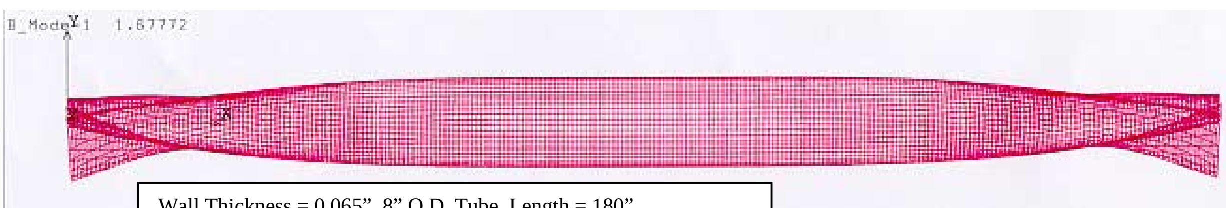
Wall Thickness = 0.120", 8" O.D. Tube, Length = 90"
Left end all 6 Degrees of Freedom Fixed, Right end upward force = 676 pounds, A thick flange was modeled on right end and pump port, external pressure = 14.7 psi, Element Size = 0.8".



Wall Thickness = 0.090", 8" O.D. Tube, Length = 90"
Left end all 6 Degrees of Freedom Fixed, Right end upward force = 676 pounds, A thick flange was modeled on right end and pump port, external pressure = 14.7 psi, Element Size = 0.8".



Wall Thickness = 0.065”, 8” O.D. Tube, Length = 14.6”
Ion Pump Port O.D. = 6”. This is a quarter symmetry model for computation of stress. The entire model is symmetrical about the Y-Z Plane and about the X-Y Plane. External Pressure = 14.7 psi.
Element Size = 0.4”.



Wall Thickness = 0.065”, 8” O.D. Tube, Length = 180”
Left and Right ends are simply supported. The ends
Do not have flanges. External pressure = 14.7 psi
There is a uniform force per unit length = 5 pounds per inch that acts along the bottom centerof the vessel, in a straight line, from one end to the other end. Element Size = 0.52”.

Material Properties for Stainless Steel used in all FEA Computations

Elastic Modulus = 29 X 10^6 psi
Poisson’s Ratio = 0.28
Shear Modulus = 11 X 10^6 psi

Singular stiffness matrices were a common occurrence for the 0.065" thick wall vessel. But for the thicker walled vessels, 0.090" and 0.120" thick, matrix singularities did not occur often. It is undetermined at this time the exact cause of these singular matrices, but it is possible that they are attributable to an elastic collapse.

It is within the scope of this analysis to run a non-linear FEA solver. A non-linear FEA solver will incrementally step the loading and then compute the stiffness matrix after each step. This tedious process is time consuming; However, it more accurately accounts for the deformation of the structure in the final solution. Unfortuneately, the non-linear "Sparse Solver" within COSMOS has a bug. I reported the bug to the Structural Research and Analysis Corporation (SRAC). If necessary, a non-linear FEA can still be done with the older "Skyline" solver within COSMOS.

SUMMARY The MathCAD computations and the COSMOS runs both confirm an intuitive prediction; The elastic instability increases non-linearly as the wall thickness decreases. This happens even though the stresses within the manifold remain well below the yield stress. Note that COSMOS buckling solutions, or eigenvalues, are theoretical solutions, and so are higher than the actual real-life critical loading, possibly by several times, depending upon the nature of the problem. So whenever COSMOS is used to find critical buckling loads of thin walled structures, the answers must be treated as an upper bound. A very approximate critical buckling load can be approximated by multiplying the theoretical critical loads by an capacity reduction factor equal to 70%. (See Los Alamos National Lab. report # LA-8853-MS for information on capacity reduction factors.) And in addition to this, another capacity reduction factor accounts for the 3" diameter tees on the top side of the vessel. For a 3" diameter tee the capacity reduction factor could be estimated as 25%, although this figure comes from a table based on plates, not tubes. (See Los Alamos National Lab. report # LA-8853-MS for information on capacity reduction factors.)

The 1/8" thick wall manifold will have significantly more strength and robustness than the 0.065" wall vessel. According to the experts at LANSCE, pulling nipples, or tees, in the thicker walled tube should not pose a significant problem. And the additional material cost of thickening the wall is only about $10.00 per foot, which is negligible for our purposes. The added weight of the vessel is only about 150lbs. An additional 150lbs will not adversely affect the design. Remember that the similarly designed vacuum manifolds in the accelerator across the street are all 1/8" thick wall. And last, keep in mind that the 0.065" thick wall design does not satisfy the ASME code specifications.

Doug Kemp.

CC: Nathan Bultman
Mike Collier
John Bernardin

22.0 Appendix J – Vacuum Manifold Sizing Optimization

Optimization of CCL Vacuum Manifold Diameter (LST 9/1/00)

Results using the detailed time-dependent model of Section 3 of this report

The size of the manifold should be based on minimizing the pressure in the beam tube. When the *Mathematica* model of two-segments of the CCLI Module 3 is used (similar to an average CCL-II Module), then the optimal manifold diameter is 10”. This optimum occurs because of competing effects: the larger diameter increases the effective pumping speed (shown in Table I), but also increases the gas load due to the increased manifold surface area. As is seen in Table I, these results do not differ much from that with the 6” diameter case. Hence a diameter of 6” to 10” should be chosen according to mechanical concerns rather than issues with the vacuum system. Results here are for a 350 cm manifold with three 300 L/s PHI ion pumps. Fewer larger pumps would suggest that a larger diameter manifold would be optimal.

Table I. Average beam tube pressure for a CCL II module with a manifold 350-cm long that is pumped by three 300 L/s PHI ion pumps. Actual pumping speed is about 280 L/s.

	6” ID	8” ID	10” ID	12” ID
Average beam tube pressure, 10^{-8} torr	3.83	3.57	3.52	3.54
Effective pumping speed, L/s	168	197	211	218

We note that in the model a manifold section is 1/4 of the total length of 350 cm. This quarter is represented with only one subvolume and the distance betweeen the pump and subvolume location is 87.5 cm. Hence a pressure variation along the manifold is not modeled but the bellows are assumed to communicate with the manifold at the highest pressure. This conservative method actually causes the pressure along the beam tube to be flatter than actual but at a higher pressure than actual. (Dividing the manifold into additional subvolumes could be done but will not lower the final beam pressures any more than a few % - hardly worth the effort.)

Results using the estimate of pressure drop within the manifold

The pressure distribution within the manifold can be estimated with the equation below:[1]

[1] 1997 Vacuum Vol. 48, No. 10, pp 793-802

$$P(x) = Aq\left(\frac{Lx - x^2}{2w} + \frac{L}{S}\right)$$

where L = pump-to-pump distance (cm);
D = diameter (cm); q, outgassing rate (torr-lit/s/sq.cm);
w molecular conductance = $C\ L$ and C, conductance = 12.1 D^3/L;
and $A = F / L$ where F, surface area = $\pi\ D\ L$.

Then $P_{max} = Aq\left(\frac{L^2}{8w} + \frac{L}{S}\right)$ and $P_{min} = AqL / S$.

So for S = 280 L/s, $q = 10^{-10}$, L = 87.5 cm (for 3 pumps in 350 cm), then the following table can be generated for various manifold diameters.

	6" ID	8" ID	10" ID	12" ID
C (L/s)	489	1160	2266	3915
P_{max} 10^{-9} torr	1.60	2.06	2.53	3.02
P_{min} 10^{-9} torr	1.50	1.99	2.49	2.99
P_{max} / P_{min}	1.07	1.03	1.015	1.008

Table I. Calculated conductance, max and min pressures in the manifold, and flatness ratio for 3 pumps distributed along a 350-cm long manifold.

The above results show that the larger the manifold results in a more flat pressure distribution. However this calculation also shows that the larger manifold causes a greater manifold pressure. This method should not be used to determine the optimal manifold size because it does not look at the effect of diameter on the beam tube pressure. In other words, with this formula P_{min} increases linearly with diameter and is independent of conductance. Hence the benefit of increasing conductance can never compete with the increasing surface area. However with a model that includes the cavities, the increased manifold surface area (going from 6" to 8") is insignificant compared to the total surface area so that the increased manifold conductance (and effective pumping speed) does reduce the beam tube pressure. Then as the diameter increases (from 10" to 12"), the manifold surface area becomes dominant relative to the linac surface area then the gain in conductance cannot compete.

23.0 Appendix K - PLC Ladder Logic Example

```
 |P7 scroll pump
 1+--+ +-+--+/+---------+/+----------------------------------( )
 |00101 |00102         10003                                 10004
 |start |stop          thermal overload                      P7 main contactor
 |scroll|scroll
 |pump  |pump
 |      |
 |      |
 |      |
2+--+ +-+
 |10004
 |P7 auxiliary contact seals in 00101
 |
 |
 |SV6 solenoid valve - turbo foreline
 3+--+ +-+--+/+----------+ +---------------------------------( )
 |00103 |00104          10004                                00002
 |open  |close          P7 must be running                   SV6 solenoid
 |SV6   |SV6
 |      |
 |      |
 |      |
 |      |
 |      |
4+--+ +-+
 |10014
 |SV6 Position indicator open position
 |seals in 00103
 |
 |
 |P8 turbo pump
 5+--+ +-+--+/+---------+ +--------+/+----------+ +----------( )
 |00105 |00106         10014      10035        10044        00045
 |start |stop          Position   foreline     turbo fault  P8 turbo running
 |turbo |turbo         indicator  pressure
 |      |              open       okay
 |      |
 |      |
 |      |
 |      |
6+--+ +-+
 |00045
 |turbo running
 |seals in 00105
 |
 |
 |GV7 main gate valve
 7+--+ +-+--+/+---------+ +--------+/+----------+ +----------( )
 |00109 |00110     |   00045      10059       | 10039        00013
 |open  |close     |   turbo      atmosphere  | turbo fault  GV7 solenoid
 |GV7   |GV7       |   start      or low vac  |
 |      |          |   mode       in vessel   |
 |      |          |                          |
 |      |          |---+ +--------+ +---------|
 |      |          |   10045      10067       |
8+--+ +-+          |   turbo      hi-vac      |
 |10069            |   full       in vessel   |
 |Position         |   speed                  |
 |indicator        +--------------------------+
 |open position
 |seals in 00109
 |
 |
 |P9 ion pump
 9+--+ +-+--+/+---------+ +--------+/+------------------------( )
 |00161 |00162         10067      10008                        00004
 |start |stop          hi-vac     ion pump                     P9 ion pump
 |pump  |pump          in vessel  fault                        control
 |      |
 |      |
 |      |
 |      |
0+--+ +-+
 |10055
 |P9 ion pump running
 |seals in 00161
```

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